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PALEOBOTANY AND PALEOECOLOGY OF THE JOFFRE BRIDGE ROADCUT LOCALITY (PALEOCENE), RED DEER, ALBERTA

by

Georgia Lynne Hoffman ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial
fullfillment of the requirements for the degree of Master of Science

Department of Biological Sciences

Edmonton, Alberta

Fall 1995

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28 August 1995

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Faculty of Graduate Studies and Research

The undersigned certify that they have read, and recommended to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled Paleobotany and Paleoecology of the Joffre Bridge Roadcut Locality (Paleocene), Red Deer, Alberta by Georgia Lynne Hoffman in partial fulfillment of the requirements for the degree of Master of Science.

Ruth A. Stockey

Dr. Ruth A. Stockey
Supervisor

Randall J. Bayer

Dr. Randall J. Bayer

Mark Wilson

Dr. Mark V.H. Wilson

Date: August 28, 1995

Dedicated to the memory of Henry and Carol Faul of the University of Pennsylvania, for teaching me my first courses on geology and paleontology, a long time ago.

ABSTRACT

Fossil plant remains representing more than 15 families have been recovered from Joffre Bridge Roadcut in south-central Alberta. Strata lie within the Paskapoo Formation. Faunal remains, palynology and magnetostratigraphy have established a middle Paleocene age (Middle Tiffanian, Ti_3) for the strata, and allowed them to be correlated beyond the Alberta Basin with confidence. The succession of sedimentary layers records the gradual abandonment of a river channel and its development into an oxbow lake. Plant remains are common, but assemblages vary according to the environment of deposition. Foliage and reproductive structures from riparian and floodplain trees are common in most layers, and delicate aquatic plants are found in the lacustrine beds. Systematic study of the material has identified more than 25 taxa, including a new genus (Araceae), and new species of a liverwort (Ricciaceae) and the samara of an Acer-like tree (Sapindaceae/Aceraceae).

ACKNOWLEDGEMENTS

This work was supported in part by NSERC (Natural Sciences and Engineering Research Council of Canada) grant A6908 to Dr. Ruth A. Stockey. Thanks are given to Dr. Stockey for guidance and financial support throughout the course for this study, as well as for instruction and encouragement in karate, and for many a fine dinner.

Special thanks are due to Mrs. Betty Speirs of Red Deer, Alberta, whose diligent collecting activities, spanning a period of more than 15 years, produced most of the plant fossils that have been the subject of this work, as well as many insect and vertebrate fossils that have been studied by others. The many specimens that she has recovered have expanded our understanding of the Paleocene of central Alberta, and her continuing efforts will keep many paleontologists busy for a long time to come.

Dr. Mark V.H. Wilson and Dr. Randall J. Bayer are thanked for serving on my Committee, a dreary task, I'm sure. Dr. Wilson shared his knowledge of the geology of the site, gained during the excavation of vertebrate fossils, and endured many questions about the insect and fish fossils. Dr. Bayer was subjected to many questions about angiosperms and plant taxonomy, and contributed in many informative discussions of botany and other topics.

Dr. Art R. Sweet of the Geological Survey of Canada helped the author recover and study the pollen of the *Spirodela*-like plant, and kindly provided the palynological report included in Appendix C, as well as many informative discussions about the Paleocene of western North America.

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The loan of specimens for this study is greatfully acknowledged. Dr. Michael Grayum of the Missouri Botanical Garden kindly provided specimens of extant *Spirodela intermedia* and *Pistia stratiotes*, as well as helpful comments about the Lemnaceae and Araceae. The type specimens of *Azolla stanleyi* were loaned by Dr. D.L. Dilcher of the Florida Museum of Natural History. Specimens of *Spirodela scutata* were loaned by Dr. T.E. Bolton of the Geological Survey of Canada; and specimens of *Spirodela scutata* and *Pistia corrugata* were loaned by Dr. E.E. McIver and Dr. J.F. Basinger of the University of Saskatchewan Department of Geology.

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Surveyed elevation data, maps, and permission to trench the site were obtained from Alberta Transportation and Utilities personnel in Edmonton and Red Deer. Backhoe services were provided by Mr. Mike Palulis of Red Deer. The final word processing was performed by Mrs. Sandra Gilday and is much appreciated.

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LIST OF SYMBOLS AND ABBREVIATIONS

Measurement of Distance:

Å	angstrom
μ	micron
m	metre
mm	millimetre
km	kilometre

Measurement of Accelerating Potential:

kV	kilovolts

Latin Words and Abbreviations:

al.	alia (others)
cf.	confer (compare)
gen.	genus
nov.	novum (new)
sp.	species
incertae	uncertain
sedis	seat (affinity)
sensu	sense

Miscellaneous Abbreviations:

API Unit	A standard for natural gamma radiation count-rates set by the American Petroleum Institute, used in downhole geophysical logging
ARC	Alberta Research Council
GSC	Geological Survey of Canada
SEM	Scanning Electron Microscopy
TEM	Transmission Electron Microscopy
UALVP	University of Alberta Laboratory for Vertebrate Paleontology
UAPC-ALTA	University of Alberta Paleobotanical Collection

Geological Symbols and Abbreviations:

Fm	Formation
Ti_3	Middle Tiffanian Land-Mammal Age

Lithological symbols - see Appendix A

Legal Descriptions (Township and Range System):

LSD	Legal Subdivision
Sec.	Section
Tp.	Township
Rg.	Range
W4M	West of Fourth Meridian

CHAPTER 1

INTRODUCTION

Joffre Bridge Roadcut is a highly productive Paleocene fossil locality in the Red Deer River valley of south-central Alberta (Fig. 1). It was discovered by Mrs. A.E. (Betty) Speirs of Red Deer when fossiliferous beds were exposed during the relocation of Provincial Highway 11 in 1978. Numerous plant, vertebrate and insect specimens have been recovered from the site through the efforts of Mrs. Speirs, Dr. R.A. Stockey of the University of Alberta Department of Botany, and Dr. R.C. Fox, Dr. M.V.H. Wilson, Mr. D.C. Wighton, and Mr. A. Lindoe of the University of Alberta Laboratory for Vertebrate Paleontology (UALVP).

This thesis describes the stratigraphy of the site, which includes a series of distinct fossiliferous layers, and presents a systematic analysis of the megaflora. The paleoenvironments represented by the different layers, as indicated by the nature of the sediments and their included plant and animal remains, are also discussed.

LOCATION

The site is usually called the Joffre Bridge locality (e.g., Stockey and Crane, 1983; Taylor and Stockey, 1984; Demchuk, 1987). Fox (1990) called it Joffre Bridge Roadcut to distinguish it from several other sites near the bridge (Fig. 1), and that name is used in this thesis.

The Joffre Bridge Roadcut site occupies an area of roughly 10,000 square metres on the south side of Alberta Provincial Highway 11 where the road

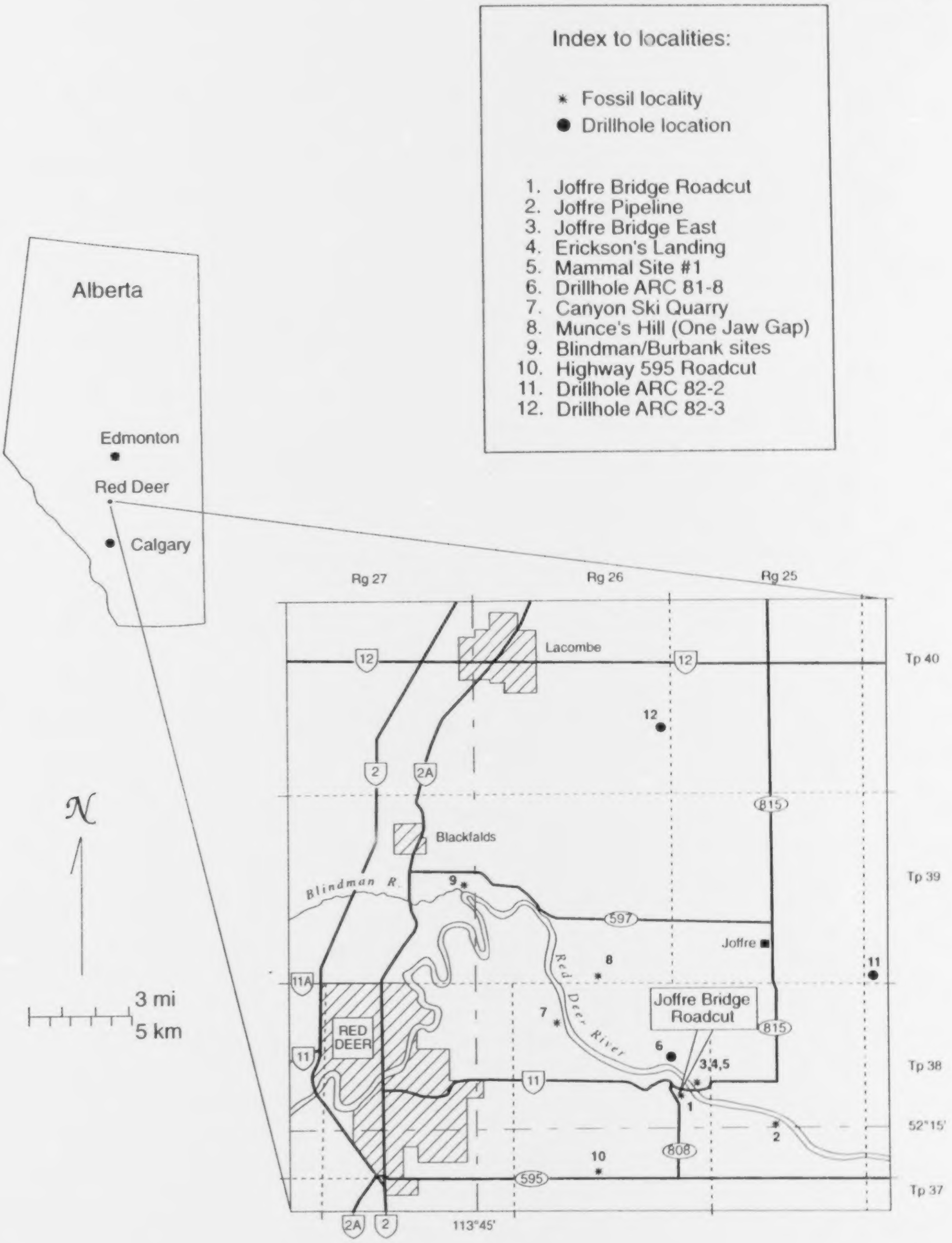

Index to localities:
* Fossil locality
● Drillhole location
1. Joffre Bridge Roadcut
2. Joffre Pipeline
3. Joffre Bridge East
4. Erickson's Landing
5. Mammal Site #1
6. Drillhole ARC 81-8
7. Canyon Ski Quarry
8. Munce's Hill (One Jaw Gap)
9. Blindman/Burbank sites
10. Highway 595 Roadcut
11. Drillhole ARC 82-2
12. Drillhole ARC 82-3
Alberta
Edmonton
Red Deer
Calgary
N
3 mi
5 km
Rg 27
Rg 26
Rg 25
Tp 40
Tp 39
Tp 38
52°15'
Tp 37
113°45'
Lacombe
Blackfalds
Joffre
RED DEER
Blindman R.
Red Deer River
Joffre Bridge Roadcut
12
2
2A
11A
11
597
815
808
595

Figure 1: Map showing fossil localities and drillholes in the Red Deer Valley area of south-central Alberta, Canada.

descends to Joffre Bridge, about 14 km west of the city of Red Deer (Figs. 1, 2). The site lies within the right-of-way for Highway 11 adjacent to farmland owned by Mr. J.D. Kaiser of Red Deer. Topographic map Red Deer 83A/5, 2nd edition (1975) (1:50,000); and Alberta Department of Highways and Transport Grading Mosaic, Highway 11:14 (1:4800), cover the site.

The site lies at 52° 16′ 10" North latitude, 113° 36′ 00" West longitude (Universal Transverse Mercator Grid 12UUN226940), Legal Subdivisions 9 & 16 of Section 14, and Legal Subdivision 12 of Section 13, Township 38, Range 26, West of 4th Meridian (Fig. 2). The Upper Level Beds (elevation about 845 m) have been quarried on the west side of the site (Section 14); the Lower Level Bed (elevation about 830 m) was quarried on the east side (Section 13).

BACKGROUND

Geologic Setting: The strata at Joffre Bridge Roadcut are of middle Paleocene age and lie within the lower Paskapoo Formation. They are part of a sequence of flat-lying Upper Cretaceous and Paleocene strata exposed along the Red Deer River valley in south-central Alberta. Those outcrops have attracted the attention of geologists and paleontologists since their first description by Tyrrell over a hundred years ago (Tyrrell, 1887). Numerous studies of the regional stratigraphy have been undertaken since that time, and large numbers of vertebrate, plant and other fossils have been recovered from a series of sites along the valley in the area where Joffre Bridge now stands (Fig. 1). Recent studies of the stratigraphic context (e.g., Richardson et al., 1988; Lerbekmo et al., 1992), faunal succession (Fox, 1990, 1991), palynology (Demchuk, 1987, 1990; Demchuk and Hills, 1991), and magnetostratigraphy (Lerbekmo et al., 1992) have established the ages of the fossil localities and their correlation with

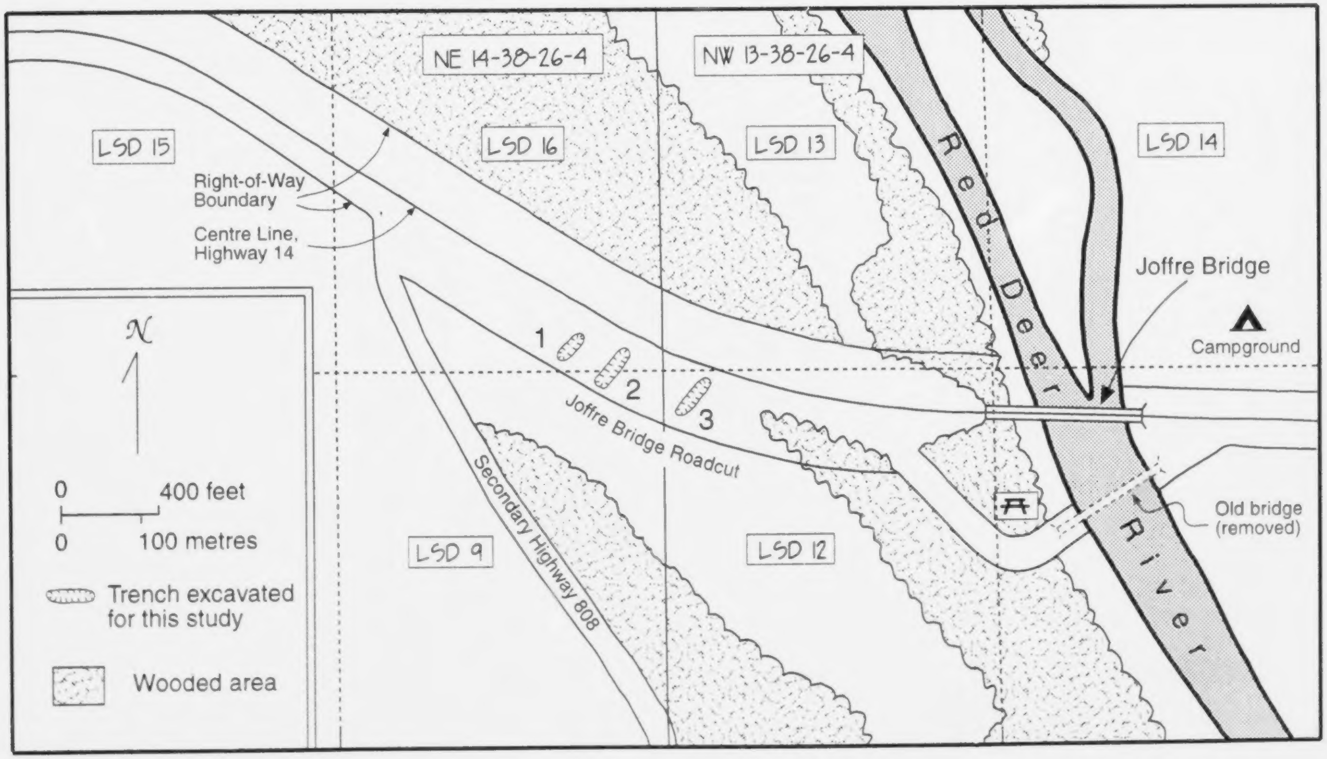

NE 14-38-26-4
NW 13-38-26-4
LSD 15
LSD 16
LSD 13
LSD 14
Red Deer River
Right-of-Way Boundary
Centre Line, Highway 14
Joffre Bridge
Campground
N
1
2
3
Joffre Bridge Roadcut
0 400 feet
0 100 metres
Trench excavated for this study
Wooded area
LSD 9
Secondary Highway 808
LSD 12
Old bridge (removed)

Figure 2: Map of Joffre Bridge area showing location of of roadcut and trenches. Base from Alberta Department of Highways and Transport, Highway 11:14 Grading Mosaic, 1:4800, aerial photography dated 26/07/75.

Paleocene sites beyond the Alberta Basin (Lerbekmo et al., 1992; Fox, 1991). Details of the regional stratigraphy and age relationships are discussed in Chapter 2.

Field Work: Paleontological work at Joffre Bridge Roadcut began in the summer of 1978. Realignment of the highway and construction of the new bridge were in progress when Mrs. Speirs noted the fossiliferous beds and began to recover specimens. She informed Dr. Stockey at the University of Alberta, and was soon joined by field parties from the Department of Botany and the UALVP. Two zones have been productive, referred to as the Lower Level and Upper Level by Fox (1990). The Lower Level (or Lower Vertebrate) Bed was worked intermittently from 1979 to 1982, and in 1986 (Fox, 1990). The Upper Level Beds, which produced the plant material described in this thesis, have been worked every summer since 1978 (Speirs, pers. comm.). Most of the quarrying has been done by hand, but the Upper Level Beds were partially cleared of brush, overburden, and accumulated waste rock by a bulldozer prior to a field trip sponsored by the Second International Organization of Paleobotany Conference in August 1984 (Taylor and Stockey, 1984), and again during work for this thesis in August, 1993 (Fig. 2 of Plate 1).

Faunal Remains: Remains of Paleocene mammals recovered from the Lower and Upper Level Beds at Joffre Bridge Roadcut have been described by Fox (1990). Remains of reptiles and amphibians (Fox. pers. comm.; M.V.H. Wilson, pers. comm.), fish (Wilson, 1980; Williams and Wilson, 1988; Wilson and Williams, 1991; Murray, 1994), insects (Kevan and Wighton, 1981; Wighton, 1982; Wighton and Wilson, 1986), and freshwater molluscs have also been recovered and reside in the UALVP Collections. Faunal remains are summarized in Appendix B.

Previous Paleobotanical Publications: Taylor and Stockey (19840 published an overview of plant remains from Joffre Bridge Roadcut. The cercidiphyllaceous plant Joffrea speirsii and its seedlings were described by Crane and Stockey (1985, 1986) and Stockey and Crane (1983). The platanaceous remains were described by Pigg and Stockey (1991). Remains of Azolla stanleyi were described by Hoffman and Stockey (1992, 1994), and the Spirodela-like plant was reported by Hoffman et al. (1995).

MATERIALS AND METHODS

The University of Alberta Paleobotanical Collection (UAPC-ALTA) currently contains more than 15,000 specimens of fossil plant remains from Joffre Bridge Roadcut, representing more than 15 families (Table 1). Most are the remains of isolated organs, but some (e.g., Ricciopsis, Azolla and the Spirodela-like plant) are whole plants. The specimens come from a succession of layers of clastic sediment ranging from claystone to medium-grained sandstone. The layers and the depositional environments that they represent are described in Chapter 3.

Compression/Impression Specimens: Almost all of the specimens are preserved as compression/impressions, and many display detailed features such as venation. The strata at Joffre Bridge Roadcut tend to break easily along bedding planes, so little preparation work is required in the laboratory. However, most of the layers are soft, poorly cemented and closely jointed, so the material tends to be rather fragile and large specimens like Platanus leaves are difficult to recover intact.

TABLE 1:
SYSTEMATICS OF PLANT TAXA FROM JOFFRE BRIDGE ROADCUT

DIVISION BRYOPHYTA

- **CLASS: HEPATICOPSIDA**
  - Order: Marchantiales
    - Family: Ricciaceae
      - *Ricciopsis* Lundblad sp.

- **CLASS: BRYOPSIDA**
  - Order: incertae sedis
    - Family: incertae sedis
      - *Muscites* Brongniart sp.

DIVISION TRACHEOPHYTA

- **CLASS: SPHENOPSIDA**
  - Order: Equisetales
    - Family: Equisetaceae
      - *Equisetum* L. sp.

- **CLASS: FILICOPSIDA**
  - Order: Filicales
    - Family: Osmundaceae
      - *Osmunda macrophylla* Penhallow
    - Family: Dennstaedtiaceae
      - *Dennstaedtia blomstrandii* (Heer) Hollick
  - Order: Salviniales
    - Family: Azollaceae
      - *Azolla stanleyi* Jain & Hall

- **CLASS: GYMNOSPERMOPSIDA**
  - Order: Ginkgoales
    - Family: Ginkgoaceae
      - *Ginkgo* L. sp.
  - Order: Coniferales
    - Family: Taxodiaceae
      - *Glyptostrobus europaeus* (Brongniart) Heer
      - *Metasequoia occidentalis* (Newberry) Chaney

SUBDIVISION: ANGIOSPERMOPHYTINA

- **CLASS: MAGNOLIOPSIDA**
  - SUBCLASS: MAGNOLIIDAE
    - Order: Ranunculales
      - Family: Sabiaceae
        - cf. *Meliosma rostellata* (Lesquereux) Crane et al.
  - SUBCLASS: HAMAMELIDAE
    - Order: Hamamelidales
      - Family: Cercidiphyllaceae
        - *Joffrea speirsii* Crane & Stockey
      - Family: Platanaceae
        - *Platanus nobilis* Newberry
        - *Macginicarpa manchesteri* Pigg & Stockey
        - *Platananthus speirsae* Pigg & Stockey
    - Order: Urticales
      - Family: Ulmaceae
        - *Chaeoptelea microphylla* (Newberry) Hickey
  - SUBCLASS: DILLENIIDAE
    - Order: Salicales
      - Family: Salicaceae
        - *Populus penhallowi* Bell
  - SUBCLASS: ROSIDAE
    - Order: Sapindales
      - Family: Sapindaceae
        - *Deviacer* Manchester sp.
        - "*Acer*" *arcticum* Heer, sensu Wolfe & Tanai

Order: Geraniales
Family: Oxalidaceae
Averrhoites affinis
(Newberry) Hickey

SUBCLASS: INCERTAE SEDIS

"Viburnum" cupanioides
(Newberry) Brown
Wardiaphyllum
daturaefolium
(Ward) Hickey
Fortuna marsilioides
(Bell) McIver &
Basinger
Unidentified aquatic leaf
Unidentified leaf 1
Unidentified leaf 2

CLASS: LILIOPSIDA

SUBCLASS: ALISMATIDAE
Order: Alismatales
Family: Alismataceae
Alismaphyllites
grandifolius
(Penhallow) Brown

SUBCLASS: ARECIDAE
Order: Arales
Family: Araceae
Spirodela-like plant

SUBCLASS: ZINGIBERIDAE
Order: Zingiberales
Family: Zingiberaceae
Zingiberopsis attenuata
Hickey

SUBCLASS: INCERTAE SEDIS
Lilialean monocot

CLASS: INCERTAE SEDIS

Unidentified seed or fruit
Striated seed
Cone-like infructescence
Unidentified branching plant
Unidentified sheathing structure

Permineralized Material: A few of the layers at Joffre Bridge Roadcut are cemented by calcite (i.e., the Mollusc Layer and the Concretion Zone; Chapter 3) but most of the included plant material was completely compressed prior to the mineralization. A few twigs and fragments of wood permineralized with calcite, and a few permineralized with limonite, were found. These were impregnated with Bio-Plastic under vacuum, and then cut and peeled to produce serial sections using an acetate peel technique with 5% HCl (Joy et al., 1956), but no cellular structure could be discerned.

Pollen, Spores and Cuticle: Pollen is not always well preserved at Joffre Bridge Roadcut, likely due to oxidizing conditions prevailing at and/or subsequent to the time of deposition. Pigg and Stockey (1991) succeeded in recovering platanaceous pollen from a crushed staminate inflorescence, but Crane and Stockey (1985) could not find any evidence of pollen in Joffrea anthers, likely due to the delicate nature of the pollen. Demchuk (1987, 1990) and Sweet (Appendix C) recovered pollen from some of the carbonaceous horizons and lacustrine beds.

Compressed Azolla megaspores, some with massulae attached, are preserved in place on many of the sporophyte specimens. Megaspores were lifted individually from sporophytes and demineralized by treatment with 5% HCl for 5 minutes, followed by 49% HF for 24 hours. They were rinsed with distilled water and cleared by treatment with 5% sodium hypochlorite for 5 to 10 minutes. Some were examined without treatment, or with bleaching only, to ensure that details were not being lost during preparation. Additional dispersed Azolla megaspores were recovered from the claystone matrix by using the "Quaternary O" method described by Hills and Sweet (1972), followed by treatment with 49% HF for 24 hours. Megaspores were picked up individually and cleared by treatment with 90% HNO_3 for 3 minutes.

Fragments of cuticle were preserved on some of the *Ricciopsis* specimens, but little evidence of cellular structure could be discerned in them. Cuticle was seldom found on specimens of other taxa.

Scanning Electron Microscopy (SEM): Materials were mounted on stubs using double-sided tape, coated with 150 Å gold by a Nanotek sputter-coater, and examined using a Cambridge Stereoscan 250 scanning electron microscope at an accelerating voltage of 20 kV.

Transmission Electron Microscopy (TEM): Materials were pipetted onto cellulose filters which were subsequently coated on both sides with agar. The agar-embedded filters were dehydrated in a graded ethanol series, transferred to 100% ethanol (with four changes to ensure complete filter removal), and gradually infiltrated with Spurr low-viscosity epoxy resin and embedded. Ultrathin sections were cut with a diamond knife, collected on uncoated copper slot grids, and dried onto Formvar support films (Rowley and Moran, 1975). Grids were stained with potassium permanganate, 1% uranyl acetate and lead citrate (Venable and Coggeshall, 1965), and examined with a Phillips EM 400T transmission electron microscope at an accelerating voltage of 80 kV.

Loaned Material: The type specimens of *Azolla stanleyi* Jain & Hall (slide 242-3) were loaned by the Florida Museum of Natural History, Gainesville, Florida, U.S.A. Two specimens of *Spirodela scutata* Dawson (GSC 3461 & 6135) were loaned by the Geological Survey of Canada, Ottawa, Ontario, Canada. Several specimens of *Spirodela scutata* and *Pistia corrugata* Lesquereux were loaned by the University of Saskatchewan Paleobotanical Collection, Saskatoon, Saskatchewan, Canada. Flowering specimens of *Spirodela intermedia* and stamens of *Pistia stratiotes* were obtained from the Missouri Botanical Garden Herbarium, St. Louis, Missouri, U.S.A.

Storage: Except for the loaned material above, all plant fossils, slides, stubs and negatives used in this thesis are housed in the University of Alberta Paleobotanical Collection (UAPC-ALTA).

CHAPTER 2

REGIONAL STRATIGRAPHY AND AGE

Flat-lying uppermost Cretaceous and Paleocene nonmarine strata are exposed over a distance of more than 100 km along the Red Deer Valley in south-central Alberta (Lerbekmo and Coulter, 1985). This sequence has received much attention from stratigraphers because of its coal resources (Richardson et al., 1988), latest Cretaceous dinosaur remains (Spalding, 1988) and mammalian fossils (Fox, 1990, 1991). Beginnning with Tyrell (1887), numerous geologists have sought to identify reliable lithostratigraphic and biostratigraphic markers that can be used to subdivide the sequence into formations and members, establish their ages, and facilitate their correlation beyond central Alberta. The history of those efforts has been described by Gibson (1977), Demchuk (1987) and Lerbekmo et al. (1992).

The sequence is divided into two major units: the Edmonton Group and the Paskapoo Formation (modified from the Edmonton Series and Paskapoo Series of Tyrell, 1887). The strata of Joffre Bridge Roadcut lie within the Paskapoo Formation, near the boundary between the Haynes and Lacombe Members (Fig. 3). The correlation of the strata in Alberta and the west-central Interior Plains is shown by Fig. 4.

Edmonton Group: The Edmonton Group is a fluvial-deltaic complex deposited during and after the withdrawal of the Bearpaw Sea from Alberta (Fig. 4). It is comprised of interbedded nonmarine clastic sediments (sandstones, siltstones, mudstones, shales, claystones, bentonites, coal seams, and carbonaceous shales),

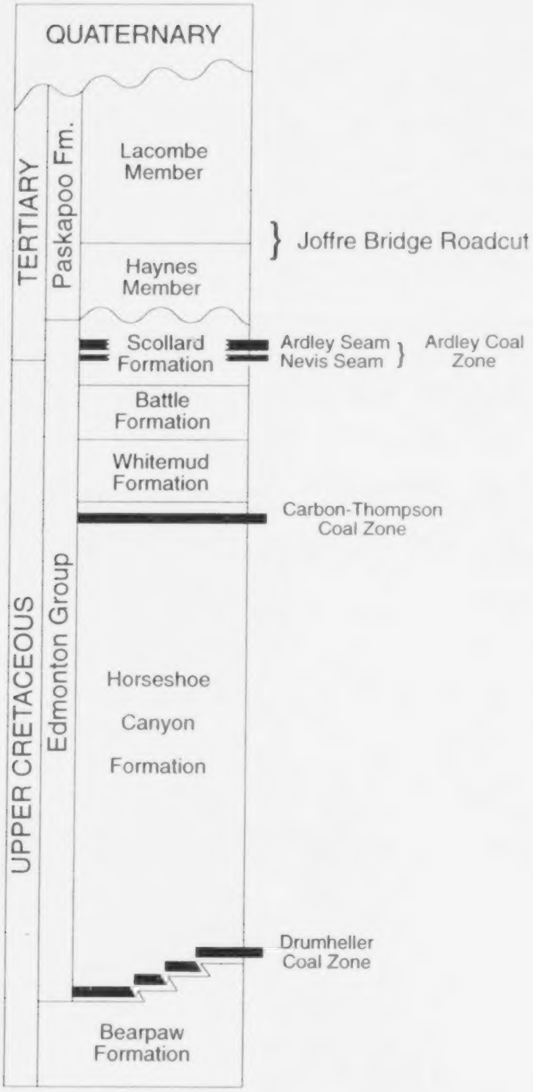

QUATERNARY
TERTIARY
Paskapoo Fm.
Lacombe Member
Haynes Member
Joffre Bridge Roadcut
Scollard Formation
Ardley Seam
Nevis Seam
Ardley Coal Zone
Battle Formation
Whitemud Formation
Carbon-Thompson Coal Zone
UPPER CRETACEOUS
Edmonton Group
Horseshoe Canyon Formation
Drumheller Coal Zone
Bearpaw Formation

Figure 3: Stratigraphy of uppermost Cretaceous and Tertiary sediments in the Red Deer Valley area of south-central Alberta. Based on Gibson (1977), Demchuk and Hills (1991), and Lerbekmo et al. (1992).

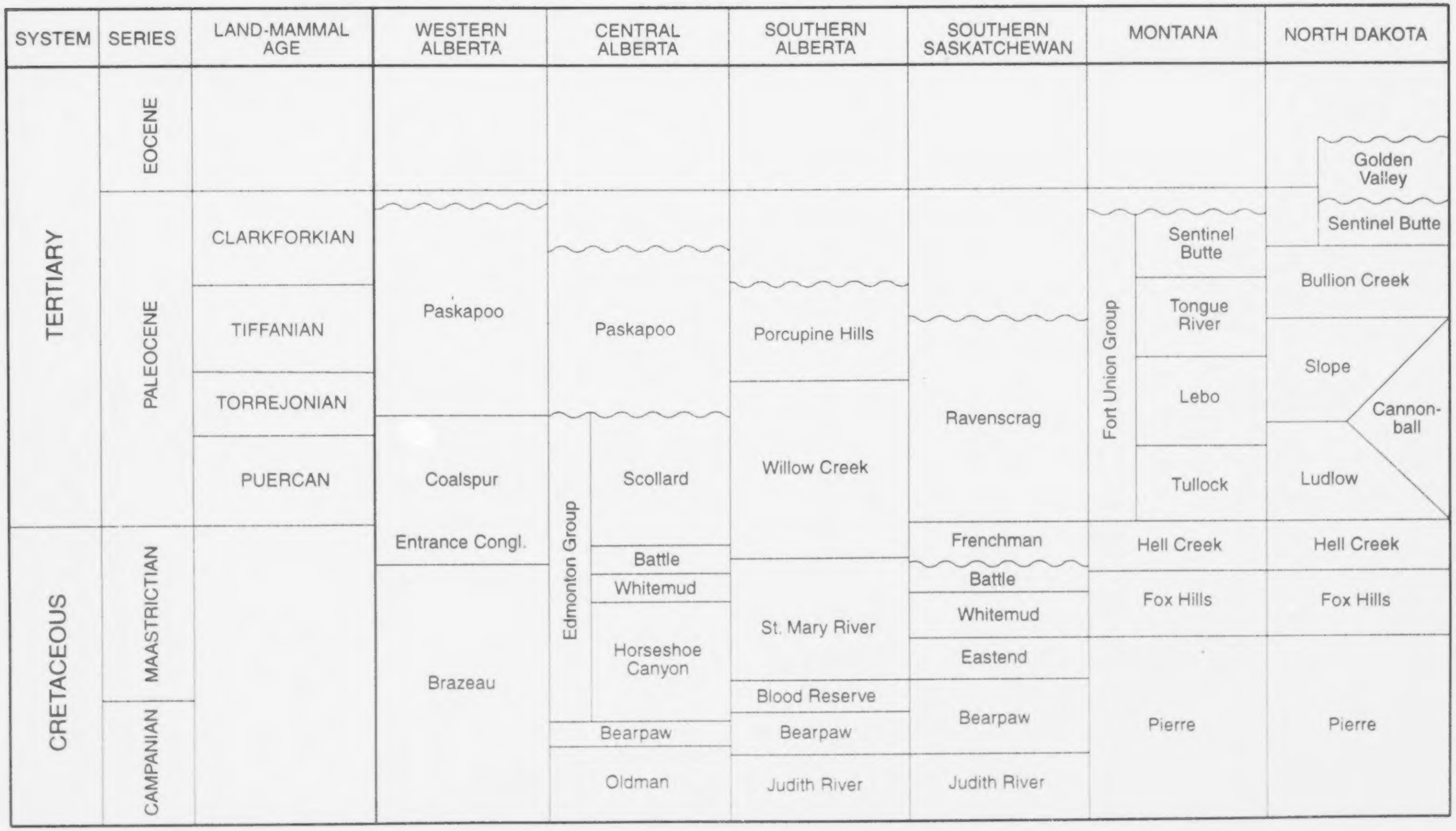

SYSTEM
SERIES
LAND-MAMMAL AGE
WESTERN ALBERTA
CENTRAL ALBERTA
SOUTHERN ALBERTA
SOUTHERN SASKATCHEWAN
MONTANA
NORTH DAKOTA
TERTIARY
CRETACEOUS
EOCENE
PALEOCENE
MAASTRICTIAN
CAMPANIAN
CLARKFORKIAN
TIFFANIAN
TORREJONIAN
PUERCAN
Paskapoo
Coalspur
Entrance Congl.
Brazeau
Paskapoo
Edmonton Group
Scollard
Battle
Whitemud
Horseshoe Canyon
Bearpaw
Oldman
Porcupine Hills
Willow Creek
St. Mary River
Blood Reserve
Bearpaw
Judith River
Ravenscrag
Frenchman
Battle
Whitemud
Eastend
Bearpaw
Judith River
Fort Union Group
Sentinel Butte
Tongue River
Lebo
Tullock
Hell Creek
Fox Hills
Pierre
Golden Valley
Sentinel Butte
Bullion Creek
Slope
Cannon-ball
Ludlow
Hell Creek
Fox Hills
Pierre

Figure 4: Correlation of uppermost Createceous and Tertiary strata in Alberta and the west-central Interior Plains. After McIver and Basinger (1993).

and is usually subdivided into the Horseshoe Canyon, Whitemud, Battle and Scollard Formations (Fig. 3) (Gibson, 1977). The Cretaceous-Tertiary boundary lies within the Scollard Formation at the base of the Nevis (No. 13) coal seam of the Ardley coal zone (Fig. 3), as evidenced by faunal and palynofloral extinctions, and the presence of an iridium anomaly (Lerbekmo et al., 1979a,b. 1987, 1990; Sweet and Hills, 1984; Lerbekmo and Coulter, 1985; Lerbekmo and St. Louis, 1986; Sweet et al., 1990).

Paskapoo Formation: The Paskapoo Formation is fluvial in origin, deposited in a tectonically active foreland basin by streams flowing eastward from the Cordillera to the Cannonball Sea (Rahmani and Lerbekmo, 1975; Gibson, 1977; Richardson et al., 1988; Lerbekmo et al., 1992). It includes interbedded fluvial sandstones, siltstones, mudstones, claystones, carbonaceous shales, and generally thin coal seams (thick seams are found only in the Obed area north of Hinton, in the uppermost part of the formation).

The contact between the Paskapoo Formation and the underlying Scollard Formation was defined by Gibson (1977) as "the base of the cliff-forming sandstone marker facies or, in the subsurface, the base of the first prominent thick sandstone unit above the uppermost major coal seam of the Ardley coal zone." However, Richardson et al. (1988) noted that those criteria are not always easy to apply in the subsurface on a regional basis, a problem that is especially pronounced in the western part of the basin where the sedimentary sequence is thickest (Richardson, pers. comm.).

In the Red Deer Valley area the contact is usually consistent with Gibson's definition. It is probably disconformable: magnetostratigraphic work by Lerbekmo et al. (1990, 1992) has demonstrated that a significant hiatus exists at the base of the Paskapoo Formation at several localities. Lerbekmo et al.

(1992) believe that this disconformity may be related to the withdrawal of the Cannonball Sea from North Dakota (Fig. 4), and may be an expression of a global unconformity caused by a mid-Paleocene decline in eustatic sea level (i.e., the Tejas A 1 to 2 supercycle boundary of Haq et al., 1985).

The Haynes Member, recently defined by Demchuk and Hills (1991), includes the thick sandstones that characterize the basal portion of the Paskapoo Formation in the Red Deer Valley area. It is 52 m thick in the type-section (ARC corehole 2-82; Fig. 1), and is composed of resistant medium- to coarse-grained sandstones and minor conglomerates, with subordinate interbeds of finer-grained sediments.

The Lacombe Member (type-section ARC corehole 3-82; Fig. 1), overlies the Haynes Member and consists predominantly of finer grained lithologies: interbedded siltstones, mudstones, shales and thin argillaceous coals, with subordinate interbeds of sandstone and conglomerate (Demchuk and Hills, 1991). Demchuk and Hills (1991) cite Taylor and Stockey's (1984) description of the paleobotany of the Joffre Bridge area in their discussion of the Lacombe Member.

The Dalehurst Member includes the youngest strata in the Paskapoo Formation. It is an erosional remnant and is present only adjacent to the Foothills in the area northeast of Hinton (Demchuk and Hills, 1991). The Dalehurst Member is not present in the Red Deer Valley area and thus is not shown on Fig. 3.

STRATIGRAPHIC POSITION OF JOFFRE BRIDGE ROADCUT

Because the strata of the Red Deer area are essentially flat-lying and undeformed, it is common practice to use elevation to determine stratigraphic position (e.g., Lerbekmo et al., 1992). This approach has occasionally caused difficulties (Lerbekmo et al., 1979b), but is usually adequate for regional studies when used with consideration of geologic context. Factors such as facies changes and differential compaction, for example, should be taken into account. The Haynes Member sandstones discussed below were deposited by fluvial channels meandering laterally within a slowly thickening floodplain, therefore the elevation of a sandstone deposited by a given channel may change gradually with distance.

The stratigraphic position of Joffre Bridge Roadcut can be illustrated by comparison with the data from drillhole ARC 8-81 (Richardson et al., 1988). That hole was drilled about 1.4 km north of Joffre Bridge Roadcut, above the cliffs across the river (Fig. 1). It penetrated to a depth of more than 250 m through the lower Paskapoo Formation and the Scollard Formation, reaching the top of the Battle Formation. The hole was not cored, but geophysical logs (natural gamma, focussed resistivity, gamma-gamma density, caliper and neutron-neutron) were recorded. Fig. 5 shows the natural gamma and focussed resistivity logs.

On Fig. 5 the thin Nevis coal seam that marks the Cretaceous-Tertiary boundary can be seen within the Scollard Formation at an elevation of 706 m above sea level. The thicker Ardley seam lies in the interval 721-725 m (coal is characterized by low count-rates on natural-gamma logs, and high resistivity responses; Hoffman et al., 1984). The Scollard Formation strata overlying the Ardley seam (in the interval 725-773 m) exhibit higher natural gamma responses and lower resistivities, indicating that they contain significant proportions of clay and silt.

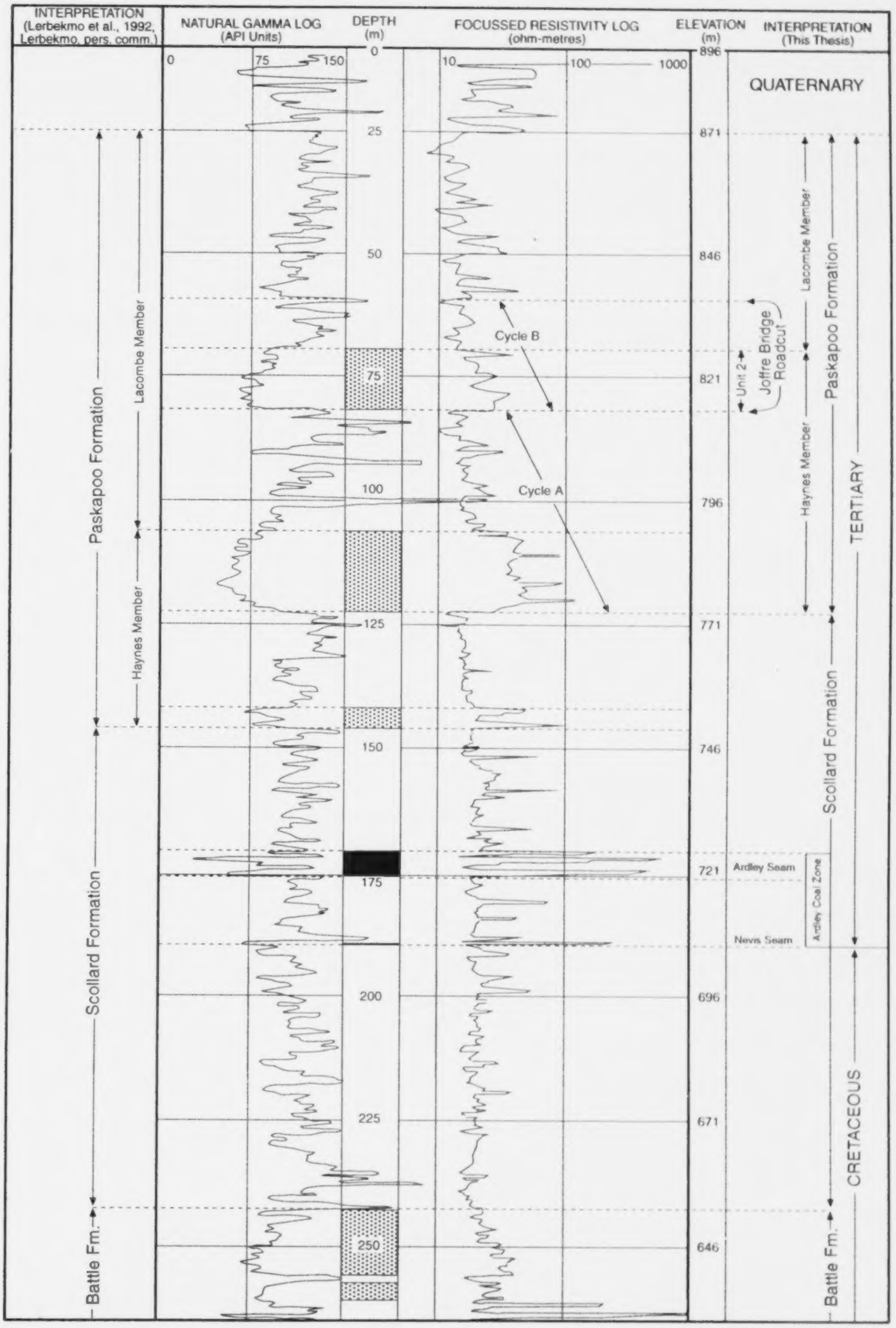


Figure 5. Geophysical logs of Drillhole ARC 81-8. See text for explanation.

The base of the Paskapoo Formation is more difficult to determine in drillhole ARC 8-81 than in other drillholes in the region (Lerbekmo, pers. comm.). An abrupt and conspicuous change to sandstone can be seen at an elevation of 773 m on Fig. 5 which is interpreted in this thesis to be the base of the Paskapoo Formation. This is consistent with the observation of Demchuk and Hills (1991) that the Haynes Member (basal Paskapoo) is easily recognized in the subsurface by its "blocky signature on gamma-ray and resistivity logs (extremely low gamma-ray and high resistivity)". However, Lerbekmo et al. (1992) placed the base of the Paskapoo at 750 m (at the base of the silty sandstone in the interval 750-754 m) because the base of the Paskapoo occurs at 750 m elevation in other drillholes in the region. The choice depends upon the amount of relief that is envisioned on the pre-Paskapoo disconformity surface, and whether a significant disconformity is considered likely to be present at the base of the silty sandstone. No core samples were taken from the drillhole, so there are no core descriptions or magnetostratigraphic data that might resolve the question. Fig. 5 compares the two interpretations.

On Fig. 5 two fining-upward cycles (sandstone to claystone) can be seen in the lower Paskapoo Formation (Cycle A at 773-814 m; Cycle B at 814-836 m). The base of each cycle is a thick layer of sandstone, but clay content increases and grain-size decreases near the top of each cycle (this evidenced by log signatures that are broad and blocky at the base and taper upward near the top). Fining-upward cycles are characteristic of fluvial channel deposits, and are generated as the river meanders back and forth across its floodplain, reworking the sediments laterally (Walker and Cant, 1984). The number of cycles preserved at any one point depends upon the meandering pattern of the river. In this thesis, Cycle A and the sandstone portion of Cycle B are interpreted as the Haynes Member. In the examples given by Demchuk and Hills (1991), the Haynes Member includes several sandstone cycles, each of which has eroded and removed most or all of the fine-grained beds at the top of the cycle beneath. On Fig. 5 the fine-grained beds at the top of Cycle A are preserved (788-814 m), but otherwise the log signature compares well with those shown by Demchuk and Hills.

Demchuk and Hills defined the contact between the Haynes and the overlying Lacombe Member as "the abrupt termination of sandstone lithologies and the presence of argillaceous and carbonaceous strata." In this thesis, that is considered to occur at the top of the Cycle B sandstone (826 m). With the base of the Paskapoo at 773 m, the thickness of the Haynes Member on Fig. 5 would then be 53 m, compared to 52 m in the type-section. In the interpretation of Lerbekmo et al. (1992), where 750 m was chosen as the base of the Paskapoo, the top of the Haynes Member was placed at the top of the Cycle A sandstone, giving a thickness of about 40 m. In that interpretation, the Cycle B sandstone was considered to be a localized channel sandstone within the Lacombe Member (Lerbekmo, pers. comm.).

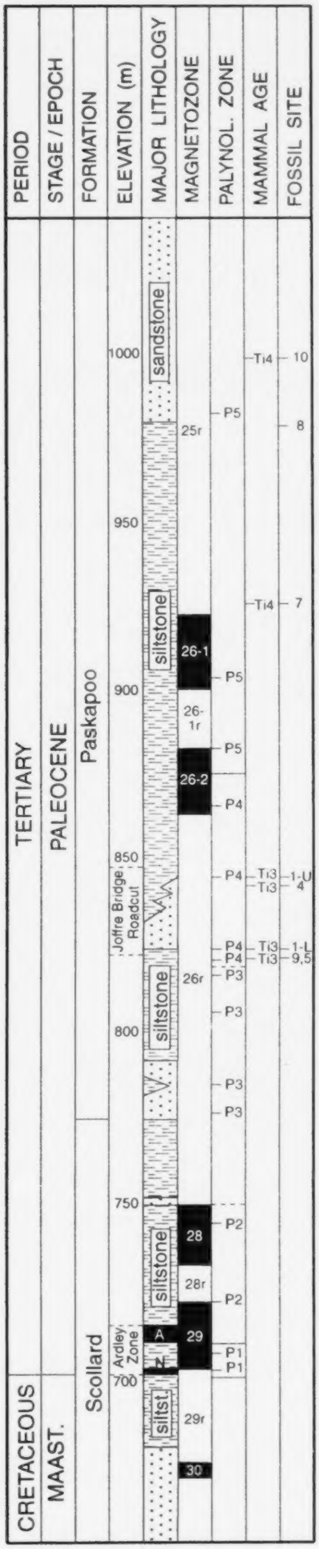
The Unit 2 sandstone at Joffre Bridge Roadcut (see Chapter 3) is likely correlative with the Cycle B sandstone on Fig. 5. The elevation of the Cycle B sandstone (814-826 m) is somewhat lower than that of the Unit 2 sandstone (830-843 m), but is within limits that would be feasible for a fluvial channel meandering across a slowly thickening floodplain, given the distance of about 1.4 km between the drillhole and Joffre Bridge Roadcut. In this case, the fossiliferous Lower Level Bed (Unit 1) that underlies the Unit 2 sandstone would then be part of the Haynes Member, and the Upper Level Beds (Units 4-6) would lie at the base of the Lacombe Member. However, if the top of the Cycle A sandstone is chosen as the top of the Lacombe Member, in accordance with Lerbekmo et al. (1992), then all of the beds would be considered to lie within the lower Lacombe Member.

AGE OF THE STRATA

Ages of Paskapoo Formation strata in the Red Deer Valley area have been determined using three independent approaches: mammalian succession (Fox, 1990, 1991); palynostratigraphy (Demchuk, 1987, 1990); and magnetostratigraphy (Lerbekmo et al., 1992). All of those studies have incorporated material from Joffre Bridge Roadcut and neighbouring fossil localities. The results of the methods are in good agreement with one another, and are summarized by Fig. 6. Radiometric dates are not available for the Paskapoo strata, but in the underlying Scollard Formation potassium-argon dates have been determined using sanadines from bentonites within the Ardley coal zone (Lerbekmo et al., 1979a).

Biostratigraphy: North American Land-Mammal (Mammal) Ages (Wood et al., 1941), which have become the primary chronological reference for Tertiary nonmarine sediments in North America, are based on the rapid evolution and dispersal of mammals during the Tertiary. The time-relations for the fossils are known principally from evolutionary changes, and secondarily from stratigraphic superposition, supported where possible by radiometric dates and, more recently, by magnetostratigraphy (Woodburne, 1987a; Lindsay et al., 1987). Mammal remains from the Red Deer Valley have been collected and studied by Fox (1990) who judged those from Joffre Bridge Roadcut to represent a Mammal Age of middle Tiffanian, Ti_3 zone (Plesiadapis rex/P. churchilli lineage-zone) (Archibald et al., 1987) (Fig. 6).

A number of palynostratigraphic time-scales have been proposed for the Paleocene of the Western Interior of North America, but because palynofloral assemblages can differ in composition depending on local and regional paleoclimatic and paleoenvironmental factors, only a small percentage of taxa



LEGEND

FOSSIL SITES (see also Fig. 1)

1-L	Joffre Bridge Roadcut, Lower Beds
1-U	Joffre Bridge Roadcut, Upper Beds
4	Erickson's Landing
5	Mammal Site #1
7	Canyon Ski Quarry
8	Munce's Hill (One Jaw Gap)
9	Blindman/Burbank
10	Highway 595 Roadcut

MAMMAL AGES

Ti3 - Ti4 After Fox (1990)

PALYNOLOGICAL ZONES

P1 - P5 After Demchuk (1990)

MAGNETOZONES (Terminology after Harland et al., 1982)

28	Normal Polarity
28r	Reversed Polarity

LITHOLOGIES

⁙	Sandstone, with minor siltstone & mudstone
▤	Siltstone & mudstone, with minor sandstone
■	Coal & carbonaceous shale

Figure 6: Summary of biostratigraphic and magnetostratigraphic data for the Red Deer Valley area, showing the relationship between North American Land-Mammal Ages, palynofloral zones, and magnetozones. Modified from Lerbekmo et al. (1992).

have proven useful for that purpose (Demchuk, 1987, 1990). Using a Momipites-Caryapollenites palynofloral lineage like that proposed by Nichols and Ott (1978) for Wyoming, but also utilizing additional angiosperm taxa, Demchuk recognized five palynofloral zones in the Red Deer Valley area. The samples that he analyzed from Joffre Bridge Roadcut fell within his P4 (Caryapollenites wodehousei) Zone (Fig. 6).

Magnetostratigraphy: The development of the Magnetic Polarity Time Scale was triggered by the discovery that magnetic reversals recorded in igneous rocks are time-dependent (Cox et al., 1963), and that the history of such reversals is recorded in oceanic basalts and marine sediments (Vine and Matthews, 1963). The technique was subsequently extended to nonmarine sediments, including those at critical localities for Mammal Ages (e.g., Lindsay et al., 1987; Butler et al., 1987). Because the magnetostratigraphic approach is independent of the paleoclimatic and paleoenvironmental factors that can affect mammal and pollen distribution, it provides an independent basis for correlation within and between sedimentary basins, as well as between marine and nonmarine strata (Woodburne, 1987a,b). Because many system, series and stage boundaries are defined in terms of marine faunal extinctions, this facilitates the global correlation of nonmarine strata.

Lerbekmo and his colleagues have conducted magnetostratigraphic studies of uppermost Cretaceous to middle Paleocene strata in south-central to southern Alberta, southern Saskatchewan and North Dakota (e.g., Lerbekmo and Coulter, 1984, 1985; Lerbekmo, 1985, 1987, 1989; Lerbekmo et al., 1992), and have used magnetostratigraphy to correlate the Red Deer Valley strata with the well-known marine foraminiferal section at Gubbio, Italy (Lerbekmo and Coulter, 1985; Alvarez et al., 1977). Although the picture in south-central Alberta is complicated by the sub-Paskapoo disconformity which removed variable amounts of polarity zones 28 and 28r, Lerbekmo et al. (1992) found that Joffre Bridge Roadcut and the other Red Deer Valley Ti_3 sites of Fox (1990) fell within the 26r reverse polarity zone (Fig. 6).

Conclusion: The Red Deer Valley is the first area in North America for which faunal succession, palynostratigraphy and magnetostratigraphy have been integrated for the middle Paleocene (Lerbekmo et al., 1992). Thus, contrary to the assertion of Gingerich (1991) that the Red Deer Valley sites are "isolated localities of uncertain age", these fossil localities are part of a well-documented stratigraphic sequence that can be correlated throughout much of the world with confidence.

CHAPTER 3

SITE STRATIGRAPHY AND DEPOSITIONAL HISTORY

The bedrock at Joffre Bridge Roadcut is now poorly exposed because the slope was backfilled, recontoured and seeded after highway construction was completed. The geological history described below is based on observations that were made in quarries and trenches that were dug by hand, and in two trenches that were dug by a track-mounted backhoe. Measured sections from the trenches are included in Appendix A.

A generalized stratigraphic section for Joffre Bridge Roadcut is shown by Table 2. The depositional units are discussed below and described in detail in Appendix A. Facies relationships between the units are illustrated by Fig. 7.

SUMMARY

The lowermost Paskapoo Formation (Haynes Member) in the Red Deer Valley area includes thick sandstones deposited by meandering river systems that flowed eastward across the foreland basin, draining the tectonically active Cordillera. Complex factors influenced the shifting drainage and sedimentation patterns at that time: episodes of thrust-faulting and uplift in the Cordillera; interference from newly rising ridges in the front ranges; subsidence of the foreland basin; and changes in eustatic sea level.

The Red Deer Valley area lay east of the mountain-building activity and appears to have been a broad floodplain with little topographic relief during the deposition of the Haynes Member. The floodplain deposits grew gradually

TABLE 2:

GENERALIZED STRATIGRAPHIC SECTION FOR JOFFRE BRIDGE ROADCUT

TYPICAL UNIT THICKNESS	NAME	DESCRIPTION	(cm)
-	Quaternary	Glacial till.	-
7	Crossbedded Sandstone	Sandstone, fine-grained, crossbedded.	>150
6d	Fish Layer	Mudstone, grey, silty; fish remains.	1
6c	Barren Zone	Mudstone, tan, becoming siltstone at top; scattered small molluscs.	60
6b	Aquatic Plant Zone	Mudstone & claystone, with aquatic plants & conifer fragments; molluscs; insects.	10
6a	Concretion Zone	Mudstone, grey, with calcite-cemented concretions; dicot leaves & conifer fragments.	15
5	Mollusc Layer	Mudstone & coal, dark grey & black, calcite-cemented; many small molluscs; dicot leaves & fruits; conifer fragments; mammal remains.	10
4	Lower Lacustrine Sequence	Mudstone, tan, silty; dicot leaves & fruits; molluscs; mammal & insect remains.	30
3	Channel-fill Siltstone	Siltstone, tan, yellow & green, with thin sand beds; seedlings; dicot leaves, fruits.	50
2	Fluvial Channel Sandstone	Sandstone, medium-grained, grey; mudstone clasts at base; scattered seeds, fragments of leaves.	1400
1	Lower Level Bed	Claystone, grey, soft, overlain by thin coal; mammal remains.	7
-	Grey Mudstone	Mudstone, grey; shell fragments; root traces.	

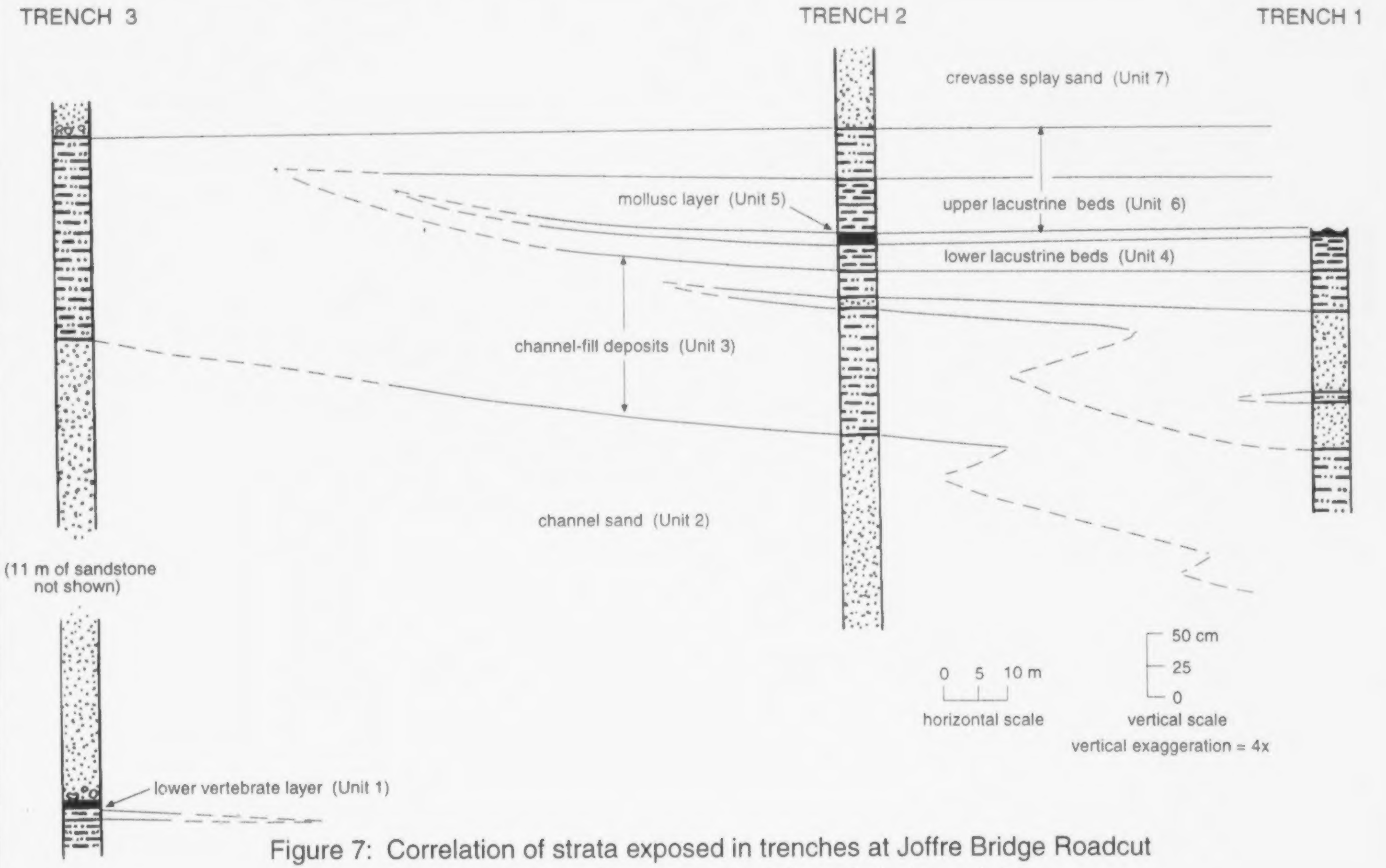

TRENCH 3
TRENCH 2
TRENCH 1
crevasse splay sand (Unit 7)
mollusc layer (Unit 5)
upper lacustrine beds (Unit 6)
lower lacustrine beds (Unit 4)
channel-fill deposits (Unit 3)
channel sand (Unit 2)
(11 m of sandstone not shown)
lower vertebrate layer (Unit 1)
0 5 10 m
horizontal scale
50 cm
25
0
vertical scale
vertical exaggeration = 4x

Figure 7: Correlation of strata exposed in trenches at Joffre Bridge Roadcut (looking south). See Appendix A for detailed trench logs.

thicker while the river channels meandered laterally across them, reworking the sediments.

The fossiliferous beds at Joffre Bridge Roadcut were deposited on the floodplain in association with a river channel. The interpreted depositional history is shown diagrammatically in Figs. 8a-d. The drawings are oriented looking south (into the outcrop) but are not to scale. The river flowed roughly eastward but the direction of flow varied locally due to meandering. The geometry of the meanders shown in the drawings is arbitrary.

The Lower Level Bed (Unit 1 below) is a thin bed of clay and coal that includes scattered bones of small vertebrates. It was deposited prior to the onset of fluvial activity at the site. The river channel itself (Fig. 8a) is represented by a thick deposit of medium-grained sandstone (Unit 2) that rests directly on top of the Lower Level Bed.

When the active channel eventually shifted eastward (Fig. 8b), deposition of the Upper Level Beds (Units 3-6) began in the abandoned channel (Fig. 8b-d). As the site became increasingly isolated from the active channel, water flow and energy levels declined, and the sediments became increasingly fine-grained, creating an environment that was well-suited to the preservation of plant and animal fossils.

The Upper Level Beds record the gradual in-filling of the abandoned channel and its development into an oxbow lake, here named Lake Speirs in honor of Mrs. Betty Speirs who collected most of the fossils from Joffre Bridge Roadcut. The channel sandstone (Unit 2) grades upward into siltstone (Unit 3; Fig. 8b), and then into lacustrine mudstones and claystones (Unit 4; Fig. 8c). The coaly mudstone of the Mollusc Layer (Unit 5) likely represents a swamp that formed

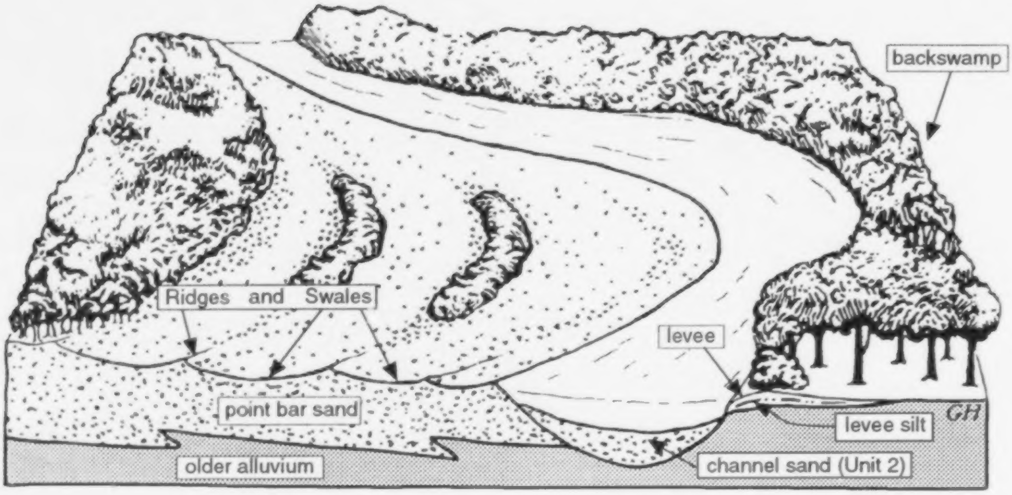

backswamp
Ridges and Swales
levee
point bar sand
levee silt
GH
older alluvium
channel sand (Unit 2)

Figure 8a: Diagrammatic illustration of sand (Unit 2) being deposited by the fluvial channel. Not to scale. See text for full explanation. Vegetation cover inspired by Wing (1984).

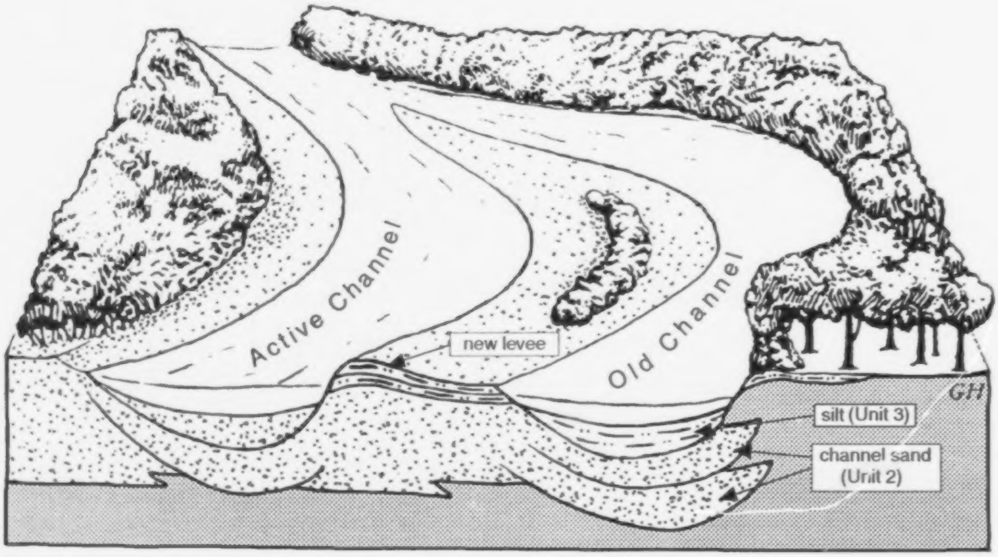

Active Channel
new levee
Old Channel
GH
silt (Unit 3)
channel sand (Unit 2)

Figure 8b: The active channel reoccupies an old swale. Silt (Unit 3) is deposited in the old channel during gradual abandonment.

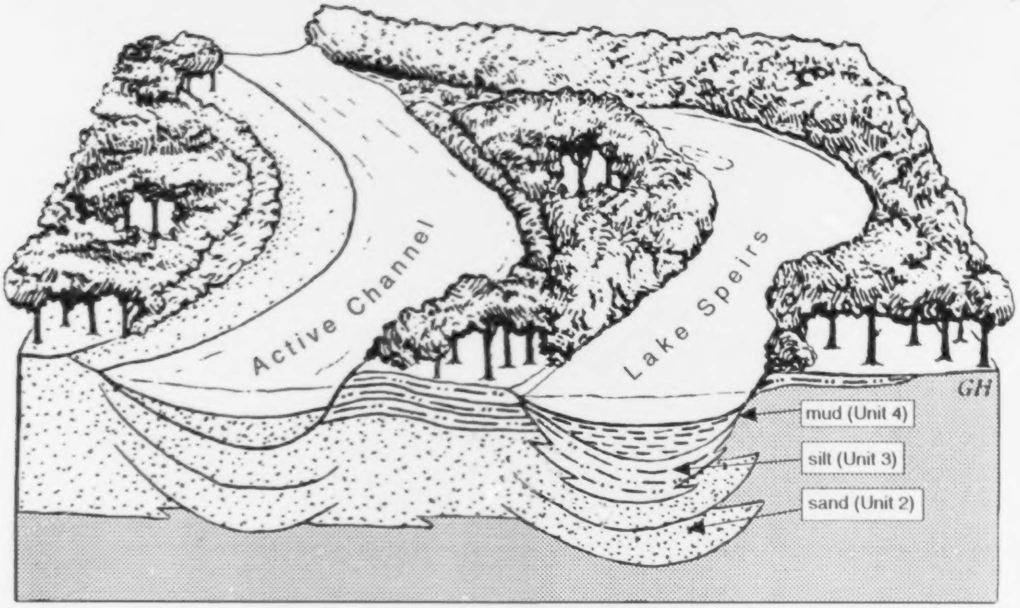

Active Channel
Lake Speirs
GH
mud (Unit 4)
silt (Unit 3)
sand (Unit 2)

Figure 8c: The old channel becomes an oxbow lake after complete abandonment and mud (Unit 4) is deposited in the lake.

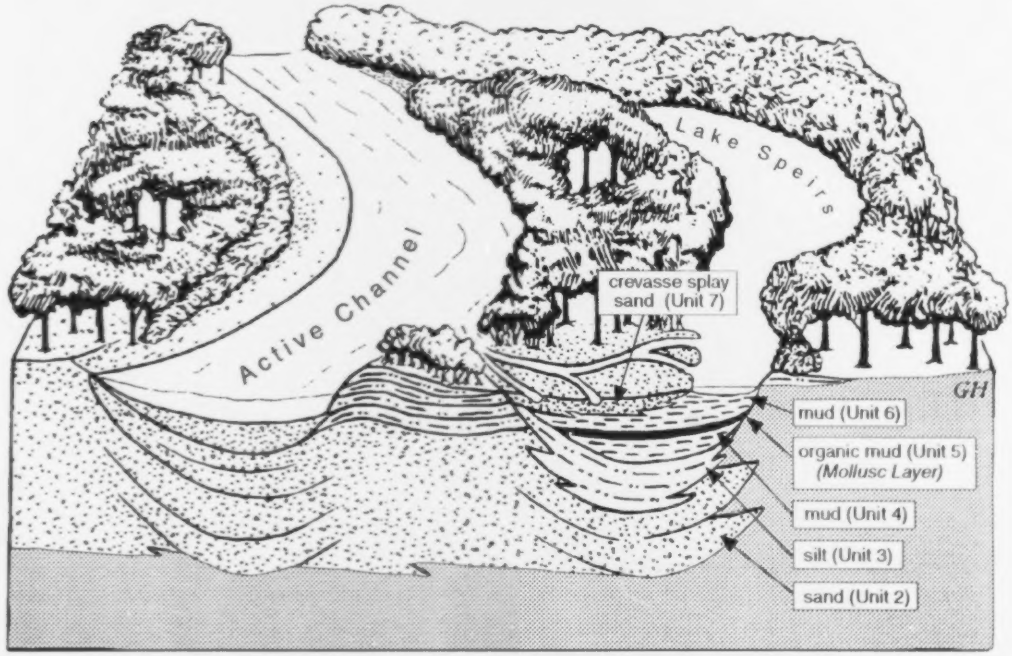

Active Channel
Lake Speirs
crevasse splay sand (Unit 7)
GH
mud (Unit 6)
organic mud (Unit 5) (Mollusc Layer)
mud (Unit 4)
silt (Unit 3)
sand (Unit 2)

Figure 8d: The levee of the active channel is breached and a crevasse splay (Unit 7) progrades into the lake over the lacustrine sediments.

during a period of low water-level in the lake. Water levels then increased again, drowning the swamp and depositing a new sequence of lacustrine mudstones and claystones (Unit 6). The sequence is capped by a crevasse-splay sandstone (Unit 7; Fig. 8d) that is unconformably overlain by glacial till.

The fossil assemblages are consistent with floodplain and oxbow lake environments (Fig. 9). Leaves and reproductive structures from large trees that preferred riparian (e.g., Joffrea and Platanus), moist (e.g., Metasequoia) and swampy (e.g., Glyptostrobus) environments can be found throughout the Upper Level Beds. Free-floating aquatic plants (Azolla, Ricciopsis, and the Spirodela-like plant) are found in some of the lacustrine beds. Shells of freshwater bivalves and gastropods are very common throughout the lacustrine and swamp layers (Units 4-6). Impressions of wings and larvae of insects that usually live near water (e.g., craneflies, dragonflies, and caddis flies) also occur in those layers. Vertebrate remains include scattered bones of soft-shelled turtles and crocodilians (Fox, pers. comm.), scales and skeletons of freshwater fish, and bones of small mammals (Appendix B).

UNIT 1: THE LOWER LEVEL BED

A bed of soft, grey clay about 4-8 cm thick forms the base of the sequence of interest at Joffre Bridge Roadcut. The clay is topped by 1-2 cm of coal. Named "Joffre Bridge Roadcut, Lower Level" by Fox (1990), this bed was quarried intermittently during 1978-1982 and 1986, producing isolated bones and teeth of small mammals, jaw fragments with teeth, and scattered reptile bones (Fox, 1990, 1991; Appendix B). Some of the jaws were oriented more or less vertically in the clay (Lindoe, pers. comm.), indicating that the bedding was disturbed by bioturbation, rooting or soil processes during or prior to the deposition of the peat that eventually became the overlying coal.

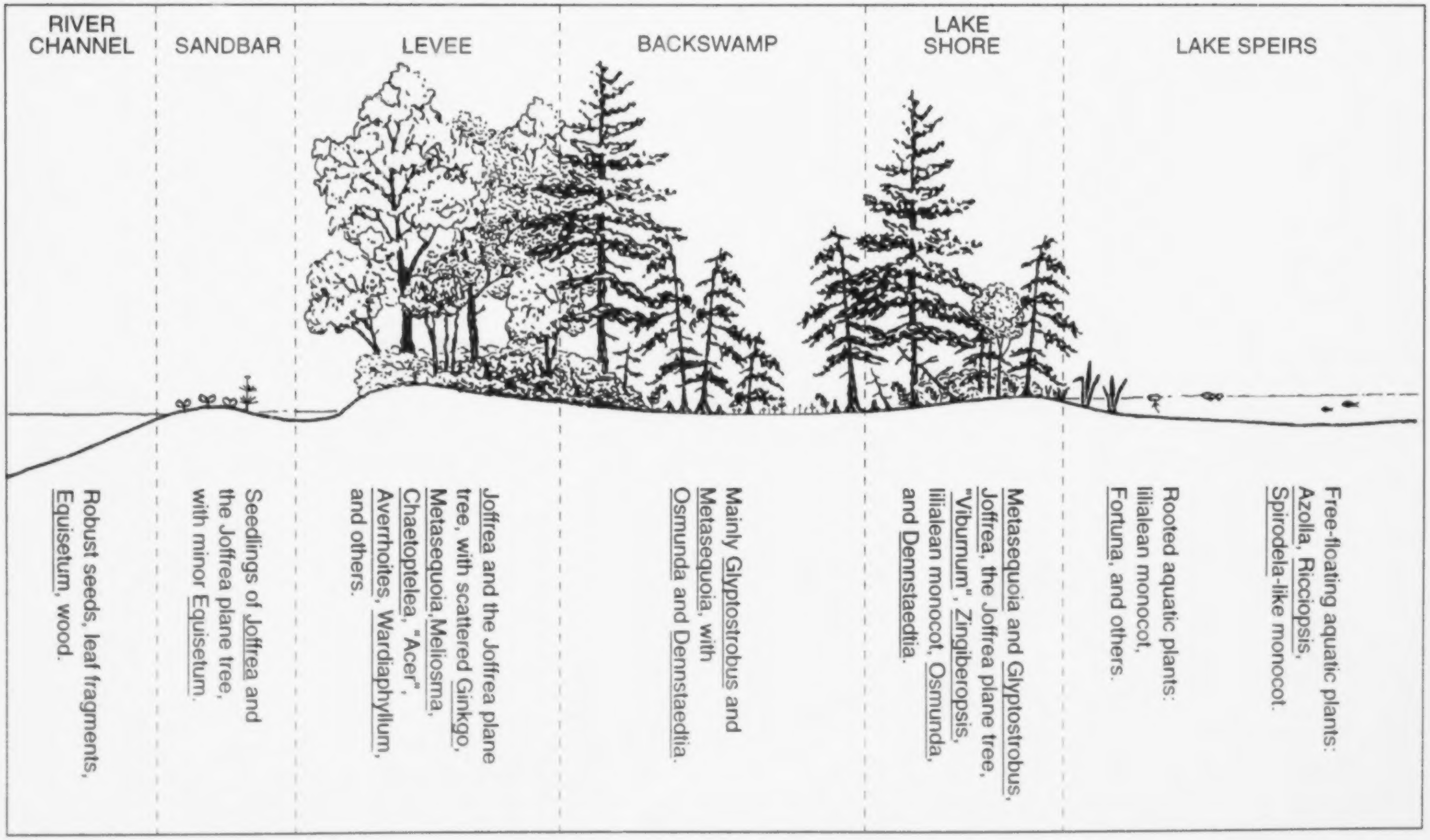

RIVER CHANNEL
SANDBAR
LEVEE
BACKSWAMP
LAKE SHORE
LAKE SPEIRS
Robust seeds, leaf fragments, Equisetum, wood.
Seedlings of Joffrea and the Joffrea plane tree, with minor Equisetum.
Joffrea and the Joffrea plane tree, with scattered Ginkgo, Metasequoia,Meliosma, Chaetoptelea, "Acer", Averrhoites, Wardiaphyllum, and others.
Mainly Glyptostrobus and Metasequoia, with Osmunda and Dennstaedtia.
Metasequoia and Glyptostrobus, Joffrea, the Joffrea plane tree, "Viburnum", Zingiberopsis, lilialean monocot, Osmunda, and Dennstaedtia.
Rooted aquatic plants: lilialean monocot, Fortuna, and others.
Free-floating aquatic plants: Azolla, Ricciopsis, Spirodela-like monocot.

Figure 9: The paleoenvironments and plant communities at Joffre Bridge Roadcut.

A thick sandstone (Unit 2) representing the bed-load of a river channel rests directly on top of the Lower Level Bed. Unit 1 may have resisted erosion during the onset of fluvial activity because of the cohesiveness of the clay and the interlocking structure of the peat material.

The Lower Level Bed is currently difficult to expose and was seen only in Trench 3 (Fig. 7). Lying near the base of the roadcut, it has become covered by slumped sediment (Fig. 2 of Plate 1).

UNIT 2: THE FLUVIAL CHANNEL SANDSTONE

The river channel at Joffre Bridge Roadcut is represented by a thick deposit of massive, medium-grained sandstone (Unit 2 in Fig. 7, 8a). As seen in Trench 3 the sandstone is about 14 m thick, with the overall fining-upward change in grain-size that is typical of sediments deposited by meandering river channels (Walker and Cant, 1984). It is coarsest at the base, where it typically includes scattered mudstone clasts and fairly robust fragments of riparian and floodplain plants such as Joffrea follicles, fragmentary dicot leaves, and coalified wood (Fig. 6 of Plate 2). It grades into siltstone near the top.

The Unit 2 sandstone at Joffre Bridge Roadcut is probably correlative with the sandstone exposed along the cliffs directly across the river. That sandstone is medium-grained and more than 10 m thick, with large-scale crossbedding in the basal portion (Fig. 5 of Plate 1). It becomes finer grained with planar bedding near the top. That sandstone overlies a thin bed of claystone similar to Unit 1, and the erosional nature of the basal contact is apparent in some of the exposures.

UNIT 3: THE CHANNEL-FILL SILTSTONE

In the western portion of the site the channel was gradually abandoned, probably by the process of chute cut-off (Walker and Cant, 1984) in which a river gradually reoccupies an old swale (Fig. 8b). Flow gradually decreases in the old channel, where deposition becomes limited to suspended or wash-load sediments (fine sand, silt and clay). The process often culminates in the formation of an oxbow lake (Fig. 8c). At Joffre Bridge Roadcut, this type of sequence was deposited in the western part of the site after the active channel shifted eastward (Unit 3 in Figs. 7, 8b). This environment was better suited to the accumulation and preservation of plant material than was the active channel.

The siltstone is tan to light green, and thin-bedded, with frequent thin interbeds of fine-grained sand. As seen near Trenches 1 and 2, the siltstone is about 35 cm thick and commonly includes scattered leaves and fruits of *Joffrea* and *Plantanus*/*Macginicarpa* as well as lenses of *Joffrea* and platanaceous seedlings. Other dicot leaves, seeds and fruits, and fish scales are also present. The lenses of seedlings indicate that parts of these sediments were occasionally emergent, perhaps as bars or mudflats that were subsequently innundated, burying the seedlings in place.

Siltstone exposed near the top of Trench 3 (Fig. 7) may be part of the Unit 3 channel-fill sequence. However, because that area lay closer to the active channel, that exposure could also represent part of a levee deposit (Fig. 8b).

UNIT 4: THE LOWER LACUSTRINE SEQUENCE

The abandoned river channel gradually became more isolated, eventually developing into an oxbow lake (Lake Speirs; Fig. 8c) with little or no direct connection to the active channel. Plant parts tended to fall or be blown in from the lakeshore plant community. Periodically the lake would have received fine sediment from the active channel during periods of high water flow and overbank flooding, during which times additional plant material would have been washed in from the active channel and the backswamps (Fig. 8c).

The Lower Lacustrine sequence (Unit 4) is present in the western part of the site (Fig. 7), where it is about 30 cm thick. It is tan to light green, thin-bedded, and silty near the base, with scattered shells of small freshwater bivalves and gastropods. It includes scattered parts of Joffrea and platanaceous remains, as well as various seeds and fruits. Insect remains include impressions of larvae and wings (Speirs, pers. comm.; Appendix B).

UNIT 5: THE MOLLUSC LAYER

Named the Mollusc Layer by Taylor and Stockey (1984), Unit 5 is a distinctive, dark grey to black, carbonaceous mudstone 6-12 cm thick that is present throughout the western part of the site (Fig. 7). It includes numerous shells of small freshwater bivalves and gastropods, and thin (0.5-2.0 cm) lenses of coal. It is well-indurated with calcite cement and very hard. The Mollusc Layer is a useful marker-bed at the site. Its dark-coloured coaly sediments contrast strongly with the lighter-coloured fluvial and lacustrine beds, and the numerous white mollusc shells give it a distinctive speckled appearance (Figs. 3, 4 of Plate 1).

The Mollusc Layer represents a swamp environment that formed during a period of low water-level in the lake. The area was isolated from the active channel, and clastic sedimentation was minimal. Small amounts of peat formed, but sufficient oxygen was available to support the population of small molluscs.

Metasequoia foliage and cones are abundant in the Mollusc Layer, as are the remains of Glyptostrobus and Platanus, and various seeds. A few fragmentary Ginkgo leaves are also found. Given the isolation of the swamp, it is unlikely that the plant remains were transported over any great distance; these taxa probably grew in or adjacent to the swamp. Isolated mammal jaws (Fox, 1990) and larvae of craneflies are also found in the Mollusc Layer (Appendix B).

UNIT 6: THE UPPER LACUSTRINE SEQUENCE

Water levels and clastic sedimentation rates in the area increased, the Mollusc Layer swamp was drowned, and a new sequence of lacustrine strata was deposited on top of it (Fig. 3 of Plate 1). The Upper Lacustrine Sequence (Unit 6) is present in the western part of the site, where it is about 85 cm thick (Fig. 6). It includes several important fossiliferous beds and has therefore been subdivided into four zones: the Concretion Zone (Unit 6a) at the base; overlain by the Aquatic Plant Zone (Unit 6b); and the Barren Zone (Unit 6c); with the Fish Layer near the top (Unit 6d) (Table 2). The overall lithology and history of the upper lacustrine sequence is summarized below, followed by detailed descriptions of the individual zones.

Initially the lake was shallow, and the lowermost mudstones and claystones contain abundant remains of swamp and shallow water plants (Unit 6a), overlain by remains of shallow water plants and free-floating aquatic taxa (Unit

6b). Insect and mammal remains have also been recovered from those beds (Appendix B).

The sediment in the overlying beds becomes coarser toward the top and is largely devoid of plant material (Unit 6c), likely due to an increasing supply of oxygenated water and coarser sediment from the active channel.

Unit 6a: The Concretion Zone

The Concretion Zone (called the Hard Layer by Taylor and Stockey, 1984) rests directly on top of the Mollusc Layer. It is about 10-15 cm thick and consists of light to medium grey mudstone with well-preserved plant and animal remains. In the westernmost part of the site (near Trench 1) the mudstone is commonly cemented into concretions by calcite; it is usually uncemented in the east (near Trench 2). Faunal remains collected from this zone (Appendix B) include insect wings and larvae (M.V.H. Wilson, pers. comm.); the skull and postcranium of a large Pantodont that Speirs found just above the Mollusc Layer (Fox, 1990; Speirs, pers. comm.); one fish (a small osteoglossomorph) and scales of a large bowfin (M.V.H. Wilson, pers. comm.).

The Concretion Zone records the inundation of the Mollusc Layer swamp by the growing lake, with increasing water levels and deposition of mud. Fragments of Glyptostrobus are abundant at the base of this zone, which may reflect the drowning of those swamp-dwelling trees. Osmunda pinnules, Metasequoia foliage, Joffrea leaves, "Viburnum" leaves, and scraps of Zingiberopsis leaves are also found, as are remains of emergent aquatic plants that grew rooted in shallow water also appear (e.g., the lilialean monocot and Fortuna).

Unit 6b: The Aquatic Plant Zone

The Aquatic Plant Zone (Unit 6b) is usually about 10 cm thick and consists of light grey to light green mudstone and claystone, with plant and insect fossils. Whole liverworts (*Ricciopsis*) and *Spirodela*-like plants, and fragments of *Typha*-like leaves, are found in the lower part of the zone. Scattered *Azolla* sporophytes, many of which are fertile, are found near the top. Insect wings (dragonfly, caddisfly and beetle) have also been found in this zone (Speirs, pers. comm.; Appendix B).

The lake was still fairly shallow when these sediments were deposited. The *Spirodela*-like plant and *Azolla* were free-floating plants that would have accumulated near the lake margins; the Lilialean monocot grew at the lake margin; and the *Ricciopsis* likely had free-floating and attached forms like the modern *Riccia fluitans* L.

Unit 6c: The Barren Zone

The Barren Zone (Unit 6c) includes about 60 cm of light green to tan mudstone, grading into siltstone in the upper half. The sediments are mildly bioturbated, and include scattered small molluscs and fish scales, but almost no plant material.

The lake appears to have grown deeper during the deposition of this zone, and was probably better connected with the active channel. Water levels and sedimentation rates increased as oxygenated water and coarser sediment flowed in from the channel, and the unit grades into siltstone at the top.

Unit 6d: The Fish Layer

A mass-death layer of fish remains lies near the top of the lacustrine sequence. The Fish Layer consists of about 1 cm of medium grey, rust-stained silty mudstone, containing the skeletons of freshwater fish. It lies a few centimetres below the crossbedded sandstone (Unit 7). The Fish Layer has been quarried by UALVP since 1984. Between 1984 and 1991, UALVP recovered 45 specimens of an osmerid (smelt), 1,795 specimens of a paracanthopterygian, two articulated specimens of an osteoglossomorph, a few disarticulated bones of an amiid, and one articulated crustacean (Murray, 1994; Wilson and Williams, 1991; Williams and Wilson, 1988).

Because modern osmerid species often spawn on beaches or in streams or ponds during spring or early summer, Wilson and Williams (1991) felt that the presence of both male and female osmerids, with apparent breeding tubercules in some of the males, indicates that the fish may have died during or after an attempt to spawn, probably in spring or early summer. The increasing coarseness of the sediment in Units 6c and 7 indicates connection between the lake and an active channel, which would facilitate the passage of fish as well as water and sediment (Fig. 8d). The UALVP is continuing to work on the Fish Layer, and further taphonomic and phylogenetic studies are in progress.

UNIT 7: THE CROSSBEDDED SANDSTONE

The crossbedded sandstone (Unit 7) appears to represent a crevasse splay that prograded into the lake (Fig. 8d). Crevasse splays form when the levee of an active channel is breached, allowing sediment-laden water to escape into the adjacent floodplain, backswamps and lakes (Davis, 1992). The sediment is deposited as a delta with its own system of distributaries leading away from the channel. Unless the breached levee heals, a crevasse splay can remain active for many years, and its deltaic deposits continue to grow.

In the western part of the site the crossbedded sandstone is fine-grained and crossbedded, with climbing ripples, a few large molluscs, and scattered large concretions (Fig. 1 of Plate 1). It contains no significant plant material (Speirs, pers. comm.; Lindoe, pers. comm.). The crossbeds and ripples indicate that the sediment was prograding roughly westward from a source to the east.

In the eastern part of the site (at Trench 3), the sandstone has an erosional base, is coarser grained, and includes mudstone clasts. This coarser part of the deposit may represent one of the distributary channels near the breached levee.

The crossbedded sandstone is the youngest Paleocene unit preserved at Joffre Bridge Roadcut. It is unconformably overlain by glacial till. Younger Paleocene strata are exposed along the Red Deer Valley to the west, and are present in the upper portion of drillhole ARC 8-81 across the river (Figs. 1 and 5).

CHAPTER 4

SYSTEMATIC DESCRIPTION OF FLORA

The suprageneric classification used in this thesis has been adapted from Cronquist (1981), Parker (1982), and Stewart and Rothwell (1993). Descriptions of leaf architecture are based on Hickey (1973, 1979), Dilcher (1974), and Hickey and Wolfe (1975).

Where the material is not sufficiently well preserved to identify with confidence, the designation considered most likely is preceeded by cf. (i.e., cf. Meliosma rostellata). A generic name in quotations (e.g., "Acer" arcticum) indicates that the generic assignment is generally believed to be incorrect, but the name is valid, and the proper designation has not been established. Material for which no affinity could be determined is described as incertae sedis (i.e., unidentified aquatic leaf).

A number of new taxa have been recognized, and it is the intention of the author to describe, name and validly publish them after the submission of this thesis, but they are unnamed in the thesis itself. They include the Spirodela-like plant, which represents a new genus; a new species of Ricciopsis, designated Ricciopsis sp. in this thesis; and a new species of Deviacer, designated Deviacer sp. in this thesis.

Division BRYOPHYTA
Class HEPATICOPSIDA
Order MARCHANTIALES
Family RICCIACEAE
Ricciopsis Lundblad
Ricciopsis sp.
(Plate 2, Figs. 8-10)

Description: The thallus is flat, linear, ribbon-like, and dichotomously branched, with a distinct dorsal sulcus, and rounded terminal segments (Fig. 7). Generally the thallus is consistently about 1.7-2.0 mm wide, but it is occasionally abruptly constricted to 0.7 mm, and abruptly dilated to as much as 5.5 mm proximal to a dichotomy (Figs. 8, 9). The sulcus is acute, deeply impressed, and persistent (Fig. 10). The margin is smooth and lacks papillae or "cilia" (Schuster, 1992) (Fig.10). Dichotomous branching occurs in a single plane, usually with about 3-5 mm between branches, forming branched ribbons or loose, incomplete rosettes (Fig. 8). Segments up to 55 mm long with 7 dichotomies have been recovered. Fragments of cuticle adhering to the specimens show no evidence of pores or modified epidermal cells. No spores were recovered.

Occurrence: About 65 specimens have been recovered from the Upper Lacustrine Sequence, at the base of the Aquatic Plant Zone (Unit 6b).

Discussion: These remains from Joffre Bridge Roadcut have the features of a thallose liverwort gametophyte: small size, prostrate habit, and a flat, leafless body. They resemble living species of the genus *Riccia* L. that have a slender, dichotomously branched, ribbon-like thallus with a dorsal sulcus.

The genus Riccia is large, with more than 200 described species, but phenotypic variability can be extreme and species limits can be difficult to establish satisfactorily (Schuster, 1992). The structure of the thallus is very simple, and has been viewed both as an ancestral type in older theories, and more recently as highly reduced and derived (Schuster, 1966, 1992). The Riccia thallus, which has been well described by MacVicar (1926), Engel (1982), Schuster (1992), and others, is flat and ribbon-like, commonly with a dorsal groove or sulcus, and is strongly branched, often forming rosettes. The dorsal surface includes simple air-chambers that range from narrow fissures completely covered by epidermis, to larger chambers connected to the surface by fissures or rudimentary pores. Where pores are present, the epidermal cells surrounding them exhibit little or no modification. A single row of scales, sometimes rudimentary or inconspicuous, is usually present on the ventral surface. Archegonia and antheridia are scattered within the thallus, and the sporophytes, which are considered to be the most reduced in the Bryophyta (Schuster, 1966, 1992), develop embedded within the thallus. Spores are few and large (well over 50 μm in most species), and are released by the partial decay of the surrounding tissue. Spore ornamentation and wall structure are significant to intrageneric taxonomy and phylogeny (Schuster, 1992; Jovet-Ast, 1987).

Some extant species of Riccia, such as Riccia fluitans L., have two morphologically distinct forms, one terrestrial and one aquatic (MacVicar, 1926; Schuster, 1992). The terrestrial form lives attached to damp soil or mud, and in some species can survive periodic drying and/or shallow submergence. The aquatic form lives free-floating on bodies of quiet or slow-moving fresh water. In most species the floating form is sterile and lacks rhizoids or ventral scales. The thalli develop rhizoids when stranded, attaching themselves to the substrate, after which the sporophytes may develop. Vegetative propagation by fragmentation occurs in both forms.

Riccia L. and Ricciocarpus Corda are the two living genera of the family Ricciaceae, which, along with the monotypic Oxymitraceae, comprise the suborder Ricciineae of the Marchantiales (Schuster, 1966). Fossil Marchantiales have been known since 1849 when Brongniart described a fertile specimen which he named Marchantites, from Eocene strata of the Paris Basin (Lundblad, 1954). Older marchantialean fossils were subsequently found in Mesozoic sediments (Walton, 1925, 1928, 1949; Steere, 1946; Lundblad, 1954, 1955; Schuster, 1966; Jovet-Ast, 1967). The name Marchantites was emended by Walton (1925) to include only fossils with an undoubted affinity to the Marchantiaceae. For Riccia-like forms, Lundblad (1954) introduced the name Ricciopsis, which she defined to include "sterile fossil thalli of Hepatics showing closer resemblance to the Ricciineae than to any other living group".

The name Ricciopsis is appropriate for the liverwort specimens from Joffre Bridge Roadcut. Their sterile thalli resemble those of Riccia in their slender, branching, ribbon-like habit, dorsal sulcus, and lack of pores. However, because no spores or sporophytes are available, the plant is not known well enough to assign it to a living genus.

The Ricciopsis remains from Joffre Bridge Roadcut are unusual in the abrupt constrictions and dilations of the thallus that are sometimes present proximal to a dichotomy (Jovet-Ast, pers. comm.). A new specific name may therefore be warranted for this fossil.

The thalli are found in a thin bed of claystone near the base of a lacustrine sequence, scattered among the very abundant remains of a Spirodela-like plant, just as modern Riccia are commonly found floating among Spirodela and other Lemnaceae on ponds and sluggish streams (Hillman, 1961; Schuster, 1992). The deposit appears to represent an assemblage of floating plants that had become stranded together on a mudflat or shoreline immediately prior to burial.

The lack of any visible rhizoids or ventral scales and the geological setting suggest that these specimens may represent a free-floating form, like those seen in modern Riccia fluitans. It is also possible that, like the free-floating form of R. fluitans, the floating form of this plant was sterile. No ricciaceous spores were recovered from thallus fragments or the surrounding matrix despite efforts by the author and A.R. Sweet of the Geological Survey of Canada. Well-preserved lemnaceous pollen from the associated Spirodela-like plant was obtained from the samples, so the absence of spores probably cannot be attributed to poor preservation.

Class BRYOPSIDA
Family INCERTAE SEDIS
Genus Muscites Brongniart
Muscites sp.

(Plate 2, Fig. 11)

Description: Specimens consist of branching stems up to 15 mm long. Stems are about 0.2 mm wide, with branches up to 6 mm long, arising at an angle of about 35°. Leaves are alternately or helically arranged, imbricate, 2 mm long, 0.5 mm wide, symmetrical, narrow-oblong, with acute apices and bases, entire margins, apparently thin laminae, and prominent, straight costae (Fig. 11).

Occurrence: Two fragmentary specimens, UAPC-ALTA S12,519 and S16,645, have been recovered from the Channel-Fill Siltstone (Unit 3).

Discussion: The genus Muscites was established by Brongniart for fossils that are clearly mosses but whose systematic position cannot be more precisely determined (Steere, 1946), as is the case for these fragments from Joffre Bridge Roadcut. They likely represent a moss gametophyte because of their small size, their branched and creeping habit, and their symmetrical, narrow-oblong leaves with distinct, dark costae and apparently delicate laminae. They resemble a specimen from Genesee, Alberta (Lower Paleocene age) that was described by Chandrasekharam (1972, 1974), who suggested a possible relationship to the Dicranaceae or Ditrichaceae. The specimens are too fragmentary and poorly preserved, however, to allow precise identification (D.H. Vitt, pers. comm.).

Division TRACHEOPHYTA
Class SPHENOPSIDA
Family EQUISETACEAE
Genus Equisetum Linnaeus
Equisetum sp.

(Plate 2, Figs. 12, 13)

Description: Specimens consist of whorls of leaves, usually detached or rarely adhering to poorly preserved stem fragments 3-7 mm in diameter. Individual leaves have a prominent midvein, are 0.5-1.5 mm wide and 5-11 mm long, and are fused along more than half of their length (Fig. 12). Free leaf apices are 1-5 mm long, with acute tips. Fragments of axes show longitudinal ridges and furrows (Fig. 13).

Occurrence: More than 25 specimens have been recovered from the Fluvial Channel Sandstone (Unit 2), the Channel-Fill Siltstone (Unit 3), the Lower Lacustrine Sequence (Unit 4), and the Aquatic Plant Zone (Unit 6b).

Discussion: These whorls of small, partially fused leaves and fragments of axes from Joffre Bridge Roadcut are typical of those of the living genus Equisetum L., but the specimens are too incomplete and poorly preserved to consider identification to a species level. Stems and rhizomes are preserved only as short fragments, and no strobili have been found.

Forms resembling the extant genus Equisetum appear in early Mesozoic strata, and Equisetum-like remains are common in most Upper Cretaceous and early Tertiary plant fossil assemblages of the Northern Hemisphere (McIver and Basinger, 1989). Modern species are very widespread, ranging from boreal forests to tropical areas, growing at elevations of up to 4200 m (Tryon and Tryon, 1982). They inhabit a variety of moist or wet environments, including open disturbed soils, bogs, thickets, dense forests, and shores of ponds and streams, often forming dense colonies from their branching underground rhizomes (Tryon and Tryon, 1982). Most of the stratigraphic units at Joffre Bridge Roadcut represent wet environments that would have been suitable for Equisetum, and traces of Equisetum are occasionally found throughout the sequence. None of the Equisetum material is common or well-preserved, however, and most of it appears to have been reworked or transported, rather than buried in place.

Class FILICOPSIDA
Order FILICALES
Family OSMUNDACEAE
Genus *Osmunda* Linnaeus
Osmunda macrophylla Penhallow

(Plate 3, Figs. 14-16)

Description: The pinnules are alternate on the rachis (Fig. 15). They are narrow-ovate, asymmetrical, up to 38 mm long and 14 mm wide, with acute apices and obliquely truncate bases (Fig. 14). The proximal pinnules have a narrow base of attachment; distal pinnules are attached by broad bases; the terminal pinnule is basally lobed (Fig. 15). Margins are finely toothed with convex, acute-tipped serrations (Fig. 16). Venation is open dichotomous with a distinct midvein; lateral veins dichotomize one to three times before reaching a margin (Fig. 16).

Occurrence: Thirteen specimens, UAPC-ALTA S11,191, S13,007, S16,948-949, S16,952, S16,970-972, S36,908-912 have been recovered from the Upper Lacustrine Sequence, Concretion Zone and Aquatic Plant Zone (Units 6a and 6b).

Discussion: The specimens from Joffre Bridge Roadcut include part of one sterile frond and a number of isolated sterile pinnules that are consistent with *Osmunda macrophylla* as described by Penhallow (1908). Penhallow's specimens (sterile fronds) were collected "from the Red Deer River, at the mouth of the Blindman", an area which lies about 15 km northwest of Joffre Bridge Roadcut (Fig. 1, site 9) and encompasses strata of the same age (middle Tiffanian, Ti_3) (Fox, 1990). Collecting sites near the mouth of the Blindman

River, including Blindman-Burbank (Taylor and Stockey, 1984), Burbank (Fox, 1990) and Blackfalds (Hickey and Peterson, 1978), consist of exposures along the northwest bank of the Red Deer River on each side of the confluence, and along the north and east banks of the Blindman River immediately upstream of the confluence (Speirs, pers. comm.).

Bell (1949), and Taylor and Stockey (1984) have also described pinnae and pinnules of O. macrophylla that were collected near the mouth of the Blindman River, and the species has been reported from other Paleocene localities in the Ravenscrag Formation in Saskatchewan (McIver and Basinger, 1993), the Fort Union Group in North Dakota and Montana (Brown, 1962), and the Golden Valley Formation in North Dakota (Hickey, 1977). Boulter and Kvaček (1989) referred material from Tertiary localities in Spitsbergen and the Arctic of North America and Siberia to O. macrophylla Penhallow because it is "the earliest published name for this type of foliage."

The Osmundaceae have a long fossil record, first appearing in Mesozoic strata (Miller, 1971; Tidwell, 1992). Osmundaceous rhizomes are known from the Upper Cretaceous (Maastrictian) of central Alberta (Serbet, 1994), and during the Tertiary the genus was common in the swamp forests that occupied northern and Arctic areas (Boulter and Kvaček, 1989). Modern Osmunda grow primarily in habitats that are wet, usually in open or brushy areas, and occasionally in shaded forests (Tryon and Tryon, 1982).

Family DENNSTAEDTIACEAE

Genus Dennstaedtia Bernhardi

Dennstaedtia blomstrandii (Heer) Hollick

(Plate 3, Figs. 17-19)

Description: The frond is twice pinnate, with primary pinnae diverging at angles of about 40° (Fig. 17). Pinnules are alternate on rachis (Fig. 18); they are up to 11 mm long and 55 mm wide, narrow ovate, with acute apices (Fig. 19). Pinnule margins have acute-tipped serrations and acute sinuses. Venation is open dichotomous; there is no midvein, and veins dichotomize up to four times before reaching the margin (Fig. 19).

Occurrence: There are three specimens, UAPC-ALTA S16,950-951, S36-913, from the Upper Lacustrine Sequence, Concretion Zone and Aquatic Plant Zone (Units 6a and 6b).

Discussion: A few fragments of sterile fronds have been referred to Dennstaedtia blomstrandii (Heer) Hollick. Specimens of the same fern, also sterile, collected near the mouth of the Blindman River, were described by Penhallow (1902), Bell (1949) and Taylor and Stockey (1984). Penhallow referred his material to Sphenopteris blomstrandi Heer, which was later incorporated as a synonym of D. americana Knowlton (1910) by Knowlton (1919). Heer's specific name has priority, however, thus the name Dennstaedtia blomstrandii is used (e.g., Hollick, 1936; Bell, 1949; Boulter and Kvaček, 1989).

Like Osmunda, Dennstaedtia was a common fern genus of the swamp forests that occupied northern latitudes during the Tertiary (Boulter and Kvaček, 1989).

Living Dennstaedtia are found in wet mountain forests and forest openings (Tryon and Tryon, 1982).

Order SALVINIALES*
Family AZOLLACEAE
Genus Azolla Lamarck
Azolla stanleyi Jain & Hall

(Plate 4, Figs. 20 - 33)

Description: Plants are small, planar, and triangular, reaching up to 225 mm in length. The main rhizomes are up to 0.2 mm wide and bear alternately arranged lateral branches, with one leaf between succeeding branches (Fig. 21). Leaves are alternate, sessile, and imbricate, each leaf overlapping the next by 10-20%. Leaves reach up to 2 mm in length and are ovate with obtuse bases and apices, entire margins, and papillate surfaces (Fig. 22), frequently showing indications of a single unbranched midvein (Fig. 20). Ventral leaf lobes, if present, could not be discerned due to the imbrication of the leaves. Detached roots near sporophytes are 0.1 mm wide and up to 0.5 cm long; no roots were found attached.

On fertile specimens megaspores are associated with leaves along the entire length of the lateral branches (Fig. 21), occurring singly or in pairs at the bases of leaves (Fig. 22). Megasporocarps and megasporangia appear to have decayed prior to preservation, leaving the resistant megaspores lying naked on the impressions of the leaves, sometimes with massulae attached. Similarly, microsporocarps and microsporangia were not preserved, but free massulae are abundant.

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* A version of this section is published in Can. J. Bot. 72: 301-308.

Megaspore complexes are ovate (Fig. 33), ranging from 432-663 μm in length, (average 516 μm). Megaspores are nearly spherical and range from 266-452 μm in diameter (average 334 μm), inclusive of perine. The supraspore is generally as wide as the megaspore and bears more than 15 floats, roughly organized in three tiers (Fig. 23). Floats appear spherical to ovoid in surface view. The upper, innermost floats are conical (Fig. 24). Floats lack filaments and are distinct entities, loosely held by entanglement in filaments from the columella (suprafilosum of Fowler and Stennett-Willson, 1978) (Fig. 24). Megaspore and supraspore are covered by filamentous infrafilosum and suprafilosum, respectively (Fowler and Stennett-Willson, 1978). Infrafilosum is up to 4.0 μm thick, with filaments about 0.5-1.2 μm in diameter (Fig. 25), arising from the outer perine or experine (Sweet and Hills, 1971) (exoperine of Fowler and Stennett-Willson, 1978) (Fig. 27). Where infrafilosum has been removed by degradation (e.g., Fig. 24), the rugulo-reticulate texture of the experine is apparent (Fig. 26). The megaspore wall is distinctly layered. The experine ranges from 2.3-5.0 μm thick (average 3.8 μm) and consists of large sculpturing elements that are more or less solid, fused, rugulate, elongate baculae (Sweet, 1972), separated by pit-like depressions reaching the inner perine (Figs. 12, 13). The inner perine or inperine (Sweet and Hills, 1971) (endoperine of Fowler and Stennett-Willson, 1978) is 1.3-3.4 μm thick (average 2.0 μm) with tangentially oriented alveolae (Saunders and Fowler, 1992, 1993). The exine is 1.8-3.4 μm thick (average 2.3 μm), alveolate and more dense than the inperine (Fig. 27). Apart from occasional effects of degradation, megaspores from the dispersed population did not differ from those found in place on sporophytes.

Massulae adhere to megaspores by entanglement of their glochidia in the filosum (Fig. 28). They are roughly ovate, typically about 125 by 200 μm in size, sometimes entangled together in large clumps. Glochidia 17-33 μm long, with fluked tips, arise from the massula surface (Figs. 28, 31), in some cases densely covering the massula. Glochidia stalks are about 0.5-1.0 μm wide at the midpoint, flaring to about 3.0 μm at the base and tip (Fig. 31). Flukes are generally 6.0-9.6 μm long. Microspores embedded within the massulae (Figs. 29, 32, 33), are circular in outline, 20-25 μm in diameter, with a rugulate surface texture and distinct trilete suture (Figs. 29, 30). Microspore walls are 0.5-1.0 μm thick and unlayered (Fig. 32). The enclosing massulae have a pseudocellular internal structure (Fowler, 1975a,b; Saunders and Fowler, 1992) (Fig. 32). Because massulae are often partly degraded and adhering to one another, it was not possible to reliably determine the number of microspores per massula.

Occurrence: More than 200 specimens have been catalogued from the Upper Lacustrine Sequence at the top of the Aquatic Plant Zone (Unit 6b).

Discussion: The genus Azolla contains small heterosporous ferns, and is classified in either the Salviniaceae or the Azollaceae. Six or seven extant species are usually recognized (Perkins et al., 1985). Plants live free-floating on the surface of quiet bodies of fresh water. The value of fossil Azolla as an environmental indicator has long been recognized (e.g., Melchior and Hall, 1983; Collinson, 1983).

Species delineation in both living and fossil Azolla is based primarily on the anatomy of the reproductive structures and the ultrastructure of the megaspore wall (Kempf, 1969; Snead, 1969, 1970; Fowler and Stennett-Willson, 1978; Calvert et al., 1983; Perkins et al., 1985). The complex reproductive structures, called megaspore complexes and massulae, are impregnated with sporopollenin (Lucas and Duckett, 1980) and are often preserved in the fossil record (Hall, 1968). Numerous fossil species ranging in age from uppermost

Cretaceous to Pleistocene have been described (Kovach and Batten, 1989; Batten and Kovach, 1990), although most are known only from dispersed megaspores and massulae. The comparatively fragile sporophyte is rarely preserved (Melchior and Hall, 1983; Saunders and Fowler, 1993).

The oldest known Azolla fossils are spore complexes of uppermost Cretaceous age (Batten and Kovach, 1990). The oldest Azolla for which sporophyte remains have been described to date are from Paleocene strata in Alberta, Saskatchewan and North Dakota: A. schopfii Dijkstra (Sweet and Chandrasekharam, 1973; McIver and Basinger, 1993); A. velus (Dijkstra) Jain & Hall (McIver and Basinger, 1993); and A. stanleyi Jain & Hall (Melchior and Hall, 1983). The spore complexes of the well-preserved Azolla from Joffre Bridge Roadcut closely resemble those of A. stanleyi, hence the material is referred to that species. The material is described below and, given the relative rarity of Azolla sporophytes, is compared with the other Paleocene species for which sporophytes are known and discussed in terms of evolutionary trends for the genus.

Azolla stanleyi (Jain and Hall, 1969) is based on dispersed megaspores and massulae from the Paleocene Sentinel Butte Formation of North Dakota. The Joffre Bridge specimens are referred to A. stanleyi because of the rugulo-reticulate texture of the experine of the megaspore wall. The ovate shape of the megaspore complex, the thick filosum arising from the experine and covering the entire megaspore complex, and the multifloated supraspore with the lowermost tier of floats overlapping the top of the megaspore, are also characteristic of A. stanleyi.

Dispersed megaspores and massulae referred to A. stanleyi have been described from the Paskapoo Formation at Wizard Lake, Alberta (Sweet, 1972) and from the Ravenscrag Formation at Estevan, Saskatchewan (Sweet, 1972; Sweet and Hills, 1976). Fertile sporophytes referred to *A. stanleyi* from the Paleocene Bullion Creek Formation at Wannagan Creek, North Dakota, have been described by Melchior and Hall (1983). These localities, the type locality and the Joffre Bridge site are all of Tiffanian age (Ti_3 and Ti_4) and *A. stanleyi* would thus appear to be a good index fossil for that time interval.

The dimensions of the megaspores and massulae of the Joffre Bridge *A. stanleyi* are quite similar to those reported by Jain and Hall (1969), Sweet and Hills (1976) and Melchior and Hall (1983). Sweet and Hills (1976) discussed size variations between the Alberta, Saskatchewan and North Dakota populations, and pointed out that these are no greater than the intrapopulation variation that they had observed in extant populations of *A. pinnata* R. Br. (Sweet and Hills, 1971).

Melchior and Hall (1983) described several (eight) "anomalous" megaspores of *A. stanleyi* "without float apparatus and with generally reduced perines and exinal elements ... frequently associated with groups of microspores that are not confined within massulae." They attributed these features to "significant differences in tapetal behavior". Some of the spores from Joffre Bridge exhibit similar characteristics (e.g., Figs. 24, 26, 29), particularly the dispersed spores that were obtained by maceration of the claystone matrix. It seems likely that these are actually normal megaspores and massulae that were partially degraded prior to burial, probably due to oxidizing conditions at the time of deposition. The megaspores and massulae in the Joffre Bridge sediments are found in varying stages of degradation, a fact that facilitates their observation under SEM. The megaspore in Fig. 24 has lost many of its floats and much of its supra- and infrafilosum. Infrafilosum has also been lost in Fig. 26. The massula in Fig. 28 is intact but has probably lost many of its glochidia. The megaspore in Fig. 24 has lost some of its infrafilosum, and the attached massulae are partially degraded, exposing the microspores.

The morphological diversity of fossil Azolla megaspores and massulae has become fairly well documented. As of 1965, only 16 fossil species had been described (Hills and Weiner, 1965), but by 1990 over 60 names had been published (Batten and Kovach, 1990). The spores of living species have also become better known through increased application of SEM and TEM since the work of Kempf (1969). Extant Azolla are usually divided into two sections: Section Azolla with three floats and fluke-tipped glochidia; and Section Rhizosperma with nine floats and massulae with few or no glochidia (Fowler, 1975a). Fossil forms with more than nine floats and fluked glochidia like A. stanleyi are referred to section Kremastospora (Jain and Hall, 1969).

Most Cretaceous and Paleocene megaspore species have more than nine floats in the supraspore, and it is now generally accepted by most researchers that a large number of floats is the plesiomorphic state (e.g., Jain and Hall, 1969; Sweet, 1972; Fowler, 1975a; Collinson, 1980; Saunders and Fowler, 1993). Evolutionary trends in massula, glochidium and columella structure remain under discussion (e.g., Fowler, 1975a; Collinson, 1980; Saunders and Fowler, 1993). Little has been written about trends in megaspore wall ultrastructure (Sweet, 1972; Collinson, 1980), despite the general agreement that this is a major taxonomic character for the genus. Modern species are distinguishable from one another on the basis of perine structure alone (Perkins et al., 1985), and the texture of the outer perine and the structure of the megaspore wall is often used to differentiate fossil species (Kempf, 1969, 1973; Snead, 1970). Analysis of the accumulated data and re-examination of other genera of fossil Salviniaceae (Hall, 1974, 1975) would likely be rewarding.

Discussion of evolutionary trends in vegetative morphology has been hampered by the limited number of fossil *Azolla* species for which vegetative material has been described (Saunders and Fowler, 1993). As of 1973, sporophytes were known for only five fossil species (Sweet and Chandrasekharam, 1973); twenty years later the number remains less than 10 (Melchior and Hall, 1983; Saunders and Fowler, 1993; McIver and Basinger, 1993). Saunders and Fowler (1993) have suggested that the evolutionary trend appears to be one of increasing adaptation to the free-floating aquatic habit, including reduction of the sporophyte, changes to the branching pattern, adoption of a planar habit, reduced vascularization of leaves, and reduced development of roots.

To date the oldest *Azolla* for which vegetative morphology has been described are from Paleocene localities: *A*. *schopfii* from lower Paleocene strata at Genesee, Alberta (Sweet and Chandrasekharam, 1973) and Ravenscrag Butte, Saskatchewan (McIver and Basinger, 1993); *A*. *velus*, also from Ravenscrag Butte (McIver and Basinger, 1993); and *A*. *stanleyi* from middle Paleocene beds at Wannagan Creek, North Dakota (Melchior and Hall, 1983) and Joffre Bridge, Alberta. A new species represented by fertile whole plants from Cretaceous-Tertiary boundary outcrops in Montana and Wyoming has also been reported (Collinson, 1991a, 1991b), but details are not yet available.

The vegetative structure of *A*. *schopfii* exhibits a number of features that Saunders and Fowler (1993) have proposed as plesiomorphic: a large overall size (up to 5 cm long), an elongate alternate branching pattern, a sub-erect growth habit, prominent leaf venation, a pubescent stem, and well developed roots in borne in large fasicles (Saunders and Fowler, 1993; Sweet and Chandrasekharam, 1973). The leaves are widely spaced along the main axis and are imbricate only at branch apices (Sweet and Chandrasekharam, 1973; Saunders and Fowler, 1993; McIver and Basinger, 1993).

In contrast, sporophytes of *A. stanleyi* indicate that most of the vegetative characteristics of modern *Azolla* were established by the middle Paleocene. The sporophytes of both *A. velus* and *A. stanleyi* seem well adapted to the free-floating habit, and exhibit features that enhance buoyancy. The sporophytes of both species are small (up to about 2 cm long), with a planar growth habit and reduced, fragile and probably solitary roots. Sporophytes of *A. stanleyi* from Joffre Bridge have a pinnate alternate branching pattern (Figs. 1. 3); those from Wannagan Creek consist of a number of rhizomes arising from a central point and radiating outward (Melchior and Hall, 1983). The leaves of *A. velus* are closely spaced but not overlapping (McIver and Basinger, 1993), while those of *A. stanleyi* are crowded and imbricate, like those of modern species. All three Paleocene species have prominent leaf venation, however, a feature not seen in modern species (Saunders and Fowler, 1993).

The Joffre Bridge sporophytes appear to shed the lowermost branches when the plant reaches about 2 cm in length (Fig. 3). While this type of asexual propagation by vegetative fragmentation was likely important in Paleocene *Azolla*, these plants also appear to have relied heavily on sexual reproduction by sporulation. Spore production can be a rare event in living species (Perkins et al., 1985), but significant percentages of the sporophytes of all three Paleocene species were fertile at the time of preservation. *Azolla stanleyi* bore sporocarps on each leaf along each lateral branch (i.e., Fig. 3), while *A. schopfii* bore sporocarps on the first leaf of each branch, like modern species (Sweet and Chandrasekharam, 1973). Abundant spore production may be a pleisomorphic character, ensuring survival under occasionally dry conditions. This may reflect an origin for heterosporous ferns in temporary pools as suggested by Wagner (1973).

Class GYMNOSPERMOPSIDA
Order GINKGOALES
Family GINKGOACEAE
Genus Ginkgo Linnaeus
Ginkgo sp.

(Pl. 5, Fig. 34)

Description: Leaves are fragmentary, reaching widths of up to about 55 mm at the apical margin. Apical margins are truncate, and undulate or irregularly lobed. Veins are numerous and equal, diverging at very low angles and branching dichotomously toward the apical margin, spaced about 0.2-0.3 mm apart (Fig. 34). No fragments with leaf bases, petioles or cuticle were found.

Occurrence: There are eight fragmentary leaves, UAPC-ALTA S9,549A/B, S11,648, S11662a, S13,072, S13,087, S13,091, S24,521, S33,552, from the Mollusc Layer (Unit 5).

Discussion: The size, apical margins, and radiating, dichotomously branching veins of these fragmentary leaves from Joffre Bridge Roadcut are consistant with those of the petiolate, fan-shaped leaves of Ginkgo L., but the specimens are too incomplete to consider identification to a species level. Fossil leaves as old as Lower Jurassic have been referred to the living genus Ginkgo (Tralau, 1968). Although the generic name Ginkgoites Seward was originally proposed for fossil Ginkgo-like leaves, it was subsequently applied to material that differs significantly from the living genus (Tralau, 1968).

At Joffre Bridge Roadcut, Ginkgo leaves have been found only in the Mollusc Layer (Unit 5), a coaly bed that was deposited in a swamp environment. Their rarity and fragmentary nature suggest that *Ginkgo* trees were not common at the site. Well preserved, whole *Ginkgo* leaves with cuticle have been found near the mouth of the Blindman River, a locality about 15 km northwest of Joffre Bridge Roadcut, where the strata are the same age (Ti_3).

Order CONIFERALES

Family TAXODIACEAE

Genus *Glyptostrobus* Endlicher

Glyptostrobus europaeus (Brongniart) Heer

(Pl. 5, Figs. 35 - 41)

Description: Fragments of branches range from stout, presumably persistent, twigs up to 100 mm long and 5 in diameter, to thinner twigs that bear alternately arranged, presumably deciduous, branchlets (Fig. 36). Leaves are helically arranged, and five morphologies (Christophel, 1973, 1976) can be recognized. Cupressoid leaves are scale-like with acute apices; the largest ones, up to 8 mm long and 3 mm wide, are borne on the stout, persistent twigs; smaller ones 1-2 mm long and 0.5 mm wide occur near the bases of deciduous branchlets (Fig. 36), and on cone-bearing twigs (Fig. 37). Cryptomeroid leaves are acicular to falcate, 3-6 mm long and 0.5-1.5 mm wide with acute apices, and are often present distal to cupressoid leaves on branchlets (Fig. 36). Crypto-cupressoid leaves are intermediate between cryptomeroid and cupressoid leaves. Taxodioid and crypto-taxodioid leaves occur on both persistent and deciduous branches; they are flat and oblong, with decurrent bases and acute to mucronate apices, ranging up to 15 mm long and 2 mm wide (Fig. 37).

Seed-cones are pyriform, up to 20 mm long and 15 mm wide, and are terminal on short twigs 5-25 mm long that bear cupressoid leaves (Figs. 35, 37). They consist of helically arranged, imbricate, nonpeltate scales that are roughly triangular, and range up to 20 mm long and 15 mm wide, depending upon their position in the cone; they broaden from a narrow base to a rounded distal margin bearing up to 11 crenate lobes (Fig. 39). Bracts are obovate, and are about two-thirds as long as the associated scale (Fig. 40). The seeds are winged, asymmetrical, and roughly triangular or "hatchet-shaped" (Silba, 1986; McIver and Basinger, 1993), up to 13 mm long and 7 mm wide (Fig. 41). The seed body is oblong, up to 6 mm long and 2 mm wide, surrounded by the asymmetrical wing. Pollen-cones consist of acute-tipped, incurved, imbricate scales. They are globose, up to 3 mm long and 3 mm wide, and are terminal on short, alternately arranged twigs that bear cupressoid leaves (Fig. 38). Pollen was sought in several cones, but none was found.

Occurrence: More than 350 specimens have been catalogued, including branchlets bearing foliage, seed-cones and pollen-cones, as well as dispersed seed-cone scales and seeds. Glyptostrobus remains are particularly common near the base of the Upper Lacustrine Sequence in the Concretion Zone (Unit 6a) and the Aquatic Plant Zone (Unit 6b); they also occur in the Channel-Fill Siltstone (Unit 3), the Lower Lacustrine Sequence (Unit 4), and the Mollusc Layer (Unit 5).

Discussion: The Glyptostrobus remains from Joffre Bridge Roadcut provide a fairly complete record of the parent plant, including twigs, foliage, seed-cones, seed-cone scales and bracts, and pollen-cones. The material is consistent with that described as Glyptostrobus nordenskioldii (Heer) Brown by Brown (1962) from the Paleocene of the western United States, and with other material assigned to G. nordenskioldii from Paleocene localities in Alberta

(Chandrasekharam, 1972, 1974; Christophel, 1973, 1976), and Saskatchewan (McIver and Basinger, 1993).

Hickey (1977) asserted that the "division of fossil members of the genus Glyptostrobus into a number of species rests on very unreliable criteria", and he questioned the priority of the species name G. nordenskioldii. He assigned Glyptostrobus material from the Paleocene of North Dakota to G. europaeus (Brongniart) Heer, because he considered G. nordenskioldii to be a later synonym of G. europaeus. Brown (1936, 1962) had separated North American Paleocene forms of Glyptostrobus from G. europaeus on the basis of: (1) the cone-scales being "on an average, shorter and broader"; (2) their occurrence as detached scales rather than as complete cones; and (3) their age (older than Miocene). Hickey (1977) reported that the size and shape of the cone-scales from Brown's material "completely overlap" those of G. europaeus; and that complete seed-cones which are "indistinguishable from those of the European form" do occur in the American species. Heer (1870) had noted the resemblance to G. europaeus when he established G. nordenskioldii for material from Spitzbergen that did not include any examples of appressed leaves. It thus seems appropriate to include the Glyptostrobus material from Joffre Bridge Roadcut in Glyprostrobus europaeus.

The anatomy and development of living Glyptostrobus have been described by Henry and McIntyre (1926), and Takaso and Tomlinson (1990). Henry and McIntyre (1926) noted that that Tertiary Glyptostrobus did not appear to differ significantly from the living species, and they remarked that "it is possible that the tree now on the verge of extinction in China is the Tertiary species unchanged". The Glyptostrobus material from Joffre Bridge Roadcut closely resemble that of the living species and does not appear to contradict that view. However, work in progress on permineralized seed-cones of Upper Cretaceous age from Drumheller, Alberta, suggests that some of the fossils may differ in the structure of the seed-cone scales (Aulenback, pers. comm.).

The genus Glyptostrobus is believed to be extinct in the wild, but a single species survived in southeastern China where Glyptostrobus trees were planted along the swampy banks of rivers and canals to strengthen them against periodic flooding (Henry and McIntyre, 1926). The trees reach heights of up to 25 m and have prominently buttressed, conical bases. They develop "knees" or pneumatophores like those of Taxodium, and like Taxodium they shed short deciduous branchlets annually. They grow on deltaic and fluvial plains, between latitudes 22° and 26°, at elevations "not exceeding a few feet above sea-level" (Henry and McIntyre, 1926). The genus has also been reported from Vietnam at elevations of up to 1000 metres (Silba, 1986).

The geological setting of the Glyptostrobus remains at Joffre Bridge Roadcut is consistent with a wet, floodplain environment, like that favored by the living trees in China. Fragments of leafy Glyptostrobus branchlets occur in most of the stratigraphic units, and are particularly common near the base of the Upper Lacustrine Sequence, in the Mollusc Layer (Unit 5), the Concretion Zone (Unit 6a) and the Aquatic Plant Zone (Unit 6b). Glyptostrobus trees may have dominated the swampy lake margins at that time, shedding their branchlets, cones and seeds into the shallow water. The associated plant remains also indicate a wet environment. They include the taxodiaceous conifer Metasequoia, and free-floating aquatic plants (a Spirodela-like plant, Ricciopsis and Azolla).

Family TAXODIACEAE

Genus Metasequoia Miki

Metasequoia occidentalis (Newberry) Chaney

(Pl. 6, Figs. 42 - 47)

Description: Fragments of branchlets up to 80 mm long have been recovered which bear oppositely arranged leaves spaced 2-3 mm apart. The leaves are "lorate-oblong" (Hickey, 1973), up to 12 mm long and 2 mm wide, with a distinct midvein, petiolate base, and acute tip (Fig. 42). Seed-cones are globose to cylindrical, up to 20 mm in diameter and 25 mm long, with oppositely arranged, peltate scales; they are borne terminally on a leafless stalk about 2 mm in diameter and more than 25 mm long (Fig. 43). Seed-cone scales are triangular, and are generally about 5-7 mm long, 2-6 mm wide, and 2-4 mm thick (Fig. 46). Seeds are winged, flat, and roughly heart-shaped, ranging up to 7 mm in diameter (Fig. 47). The oblong seed-body is 1-2 mm wide, and lies between the two lateral wings. Each wing is usually slightly wider than the seed body at the chalazal end, narrowing toward the micropylar end. The pollen-cones are oppositely arranged on specialized axes, with one cone terminal on the axis (Figs. 44, 45). They are globose to ovoid, up to 3 mm in diameter, and are borne in the axils of scale-like leaves up to 3 mm long. The sporophylls are exserted on one specimen, extending 2.5 mm beyond the enclosing sterile scales (Fig. 44).

Occurrence: More than 250 specimens have been catalogued, including foliage, coalified seed-cones, dispersed seeds, and a few pollen-cones. Metasequoia remains are found scattered throughout most of the stratigraphic section, from the Fluvial Channel Sandstone (Unit 2) to the Aquatic Plant Zone (Unit 6b).

Discussion: The foliage, seed-cones, and pollen-cones described above are typical of those of the genus Metasequoia (Hu and Cheng, 1948; Sterling, 1949; Rothwell and Basinger, 1979; Basinger, 1981, 1984; Takaso and Tomlinson, 1992). They are consistent with material described as Metasequoia occidentalis by Chaney (1951), and with other material assigned to M. occidentalis from Paleocene localities in Alberta (Chandrasekharam, 1972, 1974; Christophel, 1973, 1976) and Saskatchewan (McIver and Basinger, 1993).

The Metasequoia pollen-cones from Joffre Bridge Roadcut are particularly interesting. Each cone appears to consist of sterile scale-like leaves that overarch and enclose the sporophylls, as is typical for the genus (Rothwell and Basinger, 1979). The pollen-cones were likely mature when preserved, being as large as the largest of those described by Chaney (1951), Chandrasekharam (1972, 1974), and Christophel (1973, 1976). On some specimens the sporophylls are exserted beyond the tips of the enclosing scales (Fig. 45) to facilitate pollen escape, as occurs in the living species (Rothwell and Basinger, 1979). Each pollen-cone is subtended by a scale-like leaf that is about as long as the diameter of the cone (Figs 44, 45), although longer subtending leaves may be seen on some of the specimens illustrated by Chaney (1951) and Chandrasekharam (1972, 1974). The subtending leaves are absent on some of the Joffre Bridge specimens, perhaps reflecting Chaney's (1951) observation that those leaves are "rarely persistent."

The genus Metasequoia first appeared during the Late Cretaceous epoch, and became the dominant conifer of North American temperate floras by early Tertiary times (Basinger, 1981). A single species, M. glyptostroboides Hu and Cheng, survived into modern times in remote valleys of south-central China (Hu and Cheng, 1948; Chaney, 1948; Fulling, 1976). It reproduces naturally in cool, dark, moist forests, and thrives "along the banks of small streams, among rocks and boulders covered thickly by liverworts and mosses", and in "seepage areas at the foot of slopes where there is abundant shade and moisture" (Chu and Cooper, 1950). Associated genera in the wild in China included some closely related to those seen at Joffre Bridge Roadcut: Cercidiphyllum, Acer and Viburnum. A few Ginkgo trees were also present near the Chinese Metasequoia but were "quite certainly planted" (Chu and Cooper, 1950).

Subdivision ANGIOSPERMOPHYTINA
Class MAGNOLIOPSIDA
Subclass MAGNOLIIDAE
Order RANUNCULALES
Family SABIACEAE
Genus Meliosma Blume
cf. Meliosma rostellata (Lesquereux) Crane et al.

(Plate 7, Figs. 48,49)

Description: Subglobose structures, 5-6 mm in diameter, with a prominent keel and pore, and a smooth to slightly papillate surface (Figs. 48, 49).

Occurrence: Two specimens have been recognized (S9,912; S9,909). Their exact stratigraphic position is not known, but the matrix is consistent with the Channel-Fill Siltstone and Lower Lacustrine Sequence (Units 3-4).

Discussion: Crane et al. (1990) described similar structures from the Paleocene Sentinel Butte Formation of North Dakota as Meliosma endocarps, and assigned them to the taxon Meliosma rostellata. The type specimen for Lesquereux's taxon, Carpites rostellatus, was of Paleocene age from the Denver Formation (Lesquereux, 1878). These structures from Joffre Bridge Roadcut show some resemblance those described by Crane et al. (1990) and are tentatively referred to that taxon, but more specimens are needed to confirm this assignment.

Subclass HAMAMELIDAE
Order HAMAMELIDALES
Family CERCIDIPHYLLACEAE
Genus Joffrea Crane & Stockey
Joffrea speirsii Crane & Stockey

(Plate 7, Figs. 50 - 59)

Stockey and Crane (1983), and Crane and Stockey (1985, 1986) have published detailed descriptions of the cercidiphyllaceous remains and seedlings from Joffre Bridge Roadcut, and their works should be consulted for additional information and illustrations.

Description: Branches (long shoots) up to 130 mm long, with smooth bark and scattered circular lenticels, have been found. They bear short shoots that are usually alternately arranged, 15-45 mm long and 5-13 mm wide, with numerous crowded, diamond-shaped leaf scars. Leaves are simple and petiolate. Laminae are elliptic, ovate or obovate (Fig. 50), and are commonly 30-70 mm long and 30-80 mm wide, or occasionally larger. Margins are crenate, with crenations most prominent in the upper two-thirds of the leaf. Minute glands are set into the lamina at the tips of crenations. Apices are obtuse to rounded. Bases are rounded, cordate or truncate, with the lamina sometimes shortly decurrent down the petiole, and the venation is actinodromous. A midrib and one or two pairs of lateral primary veins diverge radially from a point at or very near the base (Fig. 50). The midrib and inner pair of primaries are usually more strongly developed than the outermost, basal primaries. Strong secondary veins arise from the midrib at and distal to the midpoint of the leaf, and diverge from the inner primaries toward the leaf margin. Brochidodromous loops are formed by secondaries from the midrib and outer secondaries from the inner primaries (Fig. 50, 51). Higher-order veins form loops closer to the margin. Polygonal areoles with branched, freely ending veinlets are well developed.

Pistillate flowers lack perianth. They are borne in inflorescences produced from axillary buds at the apex of short shoots. Each inflorescence is surrounded at the base by bud scales, and consists of a main axis 1.0-2.0 mm thick at the base and up to 65.0 mm long, bearing approximately 40 carpels, singly or in pairs, on short side branches (Figs. 52, 53). The carpels are narrowly ellipsoidal, 9.0-11.0 mm long and 3.0-4.0 mm wide, with a single longitudinal suture on the ventral surface. An abaxially coiled, persistent style is located at the apex of each carpel (Fig. 53).

Mature infructescences bear follicles spaced 6-11 mm apart on an axis 2.0-3.5 mm thick (Fig. 55). Follicles are ellipsoidal, 18-30 mm long and 5-10 mm wide. Each follicle produced numerous flat, winged seeds. Seeds are 3.5-8.0 mm long and 1.5-3.5 mm wide, and typically crescent-shaped or semicircular, with one margin convex and the other straight to concave (Fig. 56). The seed body, located at the proximal end of the wing, is elliptical to obovate, 2.0-3.5 mm long and 0.5-1.0 mm wide. Germination was epigeal, producing a thin hypocotyl and a pair of opposite, broadly ovate to oblong cotyledons (Fig. 57). Cotyledons are 2.0-4.0 mm long, 1.5-3.0 mm wide, with rounded apices and entire margins. Cotyledon venation is pinnate and camptodromous, with a distinct midrib and 2-3 pairs of opposite to subopposite secondaries (Fig. 57). The first and second seedling leaves are borne in opposite pairs, and are ovate with acute to rounded apices and obtuse bases (Fig. 58, 59). Their margins are sparsely crenate, with glandular teeth (Fig. 59).

Associated staminate inflorescences are bud-like, ovoid, 17.0-25.0 mm long and 11.0-13.0 mm wide, and are composed of about 10-20 tightly packed, helically arranged bracts (Fig. 54). Bracts are triangular, 6.0-15.0 mm long and 5.0-8.0 mm wide, with an acute or acuminate apex, and truncate base. Stamens, borne in the axils of the bracts, consist of anthers 2.0-3.5 mm long and 1.0-1.5 mm wide, without conspicuous filaments. No pollen has been found in the anthers.

Occurrence: Thousands of specimens have been catalogued, including branches, leaves, pistillate and staminate inflorescences, infructescences, follicles, seeds and seedlings. Joffrea remains are common throughout most of the stratigraphic section, from the Fluvial Channel Sandstone (Unit 2) to the Upper Lacustrine Sequence (Unit 6). The seedlings are found in discrete lenses within the Channel-Fill Siltstone (Unit 3).

Discussion: Joffre Bridge Roadcut is the type locality of the Cercidiphyllum-like plant Joffrea speirsii, which was reconstructed by Crane and Stockey (1985). Joffrea speirsii is one of the most completely understood of fossil Cercidiphyllum-like plants. The morphology of its foliage, inflorescences and infructescences is known, and the mode of attachment of the pistillate inflorescences has been demonstrated. It is also one of the few fossil plants for which germinating seeds and seedlings have been found.

Leaves, follicles and seeds that resemble those of Cercidiphyllum are common in the late Cretaceous to Tertiary nonmarine sediments of the Northern Hemisphere, but have been assigned to a large and confusing number of genera and species (Brown, 1939; Hickey, 1977; Crane and Stockey, 1985; McIver and Basinger, 1993). Heer (1876) first noted the resemblance between some fossil leaves which he had described as Grewia crenata, and those of extant Cercidiphyllum. Significant attempts to improve the classification of such leaves and/or correlate them with associated fruits and seeds have been published by Brown (1939), Chandler (1961), Wolfe (1966), Chandrasekharam (1974), Hickey (1977), Crane (1978, 1981, 1984), Tanai (1981), and others. Cercidiphyllum-like material from other Paleocene localities in Alberta and Saskatchewan has been assigned to several genera including Cercidiphyllum (Chandrasekharam, 1972, 1974; Christophel, 1973, 1976; McIver and Basinger, 1993), Trochodendroides (Bell, 1949; McIver and Basinger, 1993), Nyssidium (McIver and Basinger, 1993), and Jenkinsella (Bell, 1949).

Joffrea closely resembles Cercidiphyllum in the morphology and venation of its leaves, seedling leaves and cotyledons. It differs significantly in the morphology of the pistillate inflorescences and their mode of attachment, however, as well as in details of the morphology of shoots and staminate inflorescences, and thus Joffrea is considered to be a separate genus within the Cercidiphyllaceae. In Cercidiphyllum, a cluster of two to six free carpels, each subtended by a linear bract, is borne at the apex of a short axis (Swamy and Bailey, 1949; Crane and Stockey, 1986). In Joffrea a much longer axis bears approximately 40 carpels, singly or in pairs. This supports Swamy and Bailey's (1949) suggestion that the cluster of carples in Cercidiphyllum represents a reduced inflorescence, rather than a simple apocarpous flower as suggested by Hutchinson (1964) (Crane and Stockey, 1986).

The habitat of Joffrea appears to have been quite similar to that of living Cercidiphyllum. There are two extant species of Cercidiphyllum Siebold et Zuccarini, C. japonicum Sieb. & Zucc. and C. magnificum (Nakai) Nakai, both of which are large, wind-pollinated dioecious trees that commonly reach heights of 20-25 m or more (Sargent, 1913; Spongberg, 1979). They are native to Japan and parts of China, and *C. japonicum* has been introduced in North America and Europe because of its ornamental attributes (Dirr, 1975, 1977). Its seedlings grow quickly and can rapidly colonize suitable areas. Dirr (1975, 1977) reported that seeds "germinated within two weeks at 90 percent plus capacity", and that the seedlings responded very strongly when treated with fertilizer, reaching heights of 1.0-1.5 m by autumn. *Joffrea* may have been capable of similar performance.

Joffrea seeds are very common in the sediments at Joffre Bridge Roadcut, and were likely produced in large quantities. Evidence from the "*Nyssidium arcticum* plant" (Crane, 1984) indicates that some Paleocene *Cercidiphyllum*-like plants produced more than twice as many seeds per follicle as living *Cercidiphyllum*. Some of the *Joffrea* seeds were actually fossilized in the act of germination (Stockey and Crane, 1983; Crane and Stockey, 1985), attesting to their fertility. *Joffrea* seedlings have been found in growth position in lenses within the Channel-Fill Siltstone (Unit 3), often at densities of 20-40 plants per 10 cm^2, intermixed with about one percent platanaceous seedlings (Stockey and Crane, 1983). The seedlings are all of approximately similar ages (Figs. 57-79), suggesting more or less synchronous, rapid germination (Stockey and Crane, 1983). They were probably attempting to colonize temporarily emergent surfaces such as shorelines or sandbars when they were buried in place by an influx of sediment-laden water. These factors led Crane and Stockey (1985) to observe that "the combined evidence strongly suggests that *Joffrea* and perhaps similar *Cercidiphyllum*-like plants from the Upper Cretaceous and early Tertiary were opportunistic, "weedy" species capable of rapidly exploiting open ... floodplain habitats".

At Joffre Bridge Roadcut, _Joffrea_ remains can be found from the Fluvial Channel Sandstone (Unit 2) to the Upper Lacustrine Sequence (Unit 6). This is not surprising, given that _Joffrea_ appears have been capable of growing rapidly and producing copious amounts of leaves, inflorescences and seeds. _Joffrea_ trees must have thrived along the banks of the river system, shedding large quantities of material into the surrounding depositional environments. The close association between cercidiphyllaceous and platanaceous remains at Joffre Bridge Roadcut and other Tertiary localities is not surprising, either. Both plants appear to have favored the same types of moist floodplain and riparian environments.

Family PLATANACEAE

Genus _Platanus_ Linnaeus

Platanus nobilis Newberry (leaves)

Genus _Macginicarpa_ Manchester

Macginicarpa manchesteri Pigg & Stockey (pistillate inflorescences and infructesceneces)

Genus _Platananthus_ Manchester emend. Friis et al.

Platananthus speirsae Pigg & Stockey (staminate inflorescences)

(Plate 8 , Figs. 60-66)

Pigg and Stockey (1991) published descriptions of the platanaceous remains from Joffre Bridge Roadcut, and their work should be consulted for additional information and illustrations.

Description: The leaves, which were assigned to Platanus nobilis by Pigg and Stockey (1991), are simple and petiolate, with three palmate lobes, and sinuses about one-third as deep as the blade length (Fig. 60). Leaf apices are broadly acute, and the bases are rounded to truncate, becoming cuneate where the lamina joins the petiole. Leaf margins are serrate, with widely spaced teeth about 1.2 mm long. Leaf laminae range in size from about 42 mm wide and 34 mm long, to 210 mm wide and 280 mm long (Fig. 61). Primary venation is basally actinodromous. Moderately thick secondary veins diverge suboppositely from the primaries at angles of 30-35° and terminate in the widely spaced teeth. Tertiary veins arise at approximately right angles to secondary veins.

Pistillate inflorescences and infructescences, which were assigned to Macginicarpa manchesteri by Pigg and Stockey (1991), are globose, and borne on peduncles 10-16 mm long (Fig. 62). Peduncles are spaced about 2-10 mm apart on long reproductive axes, in a subopposite to alternate arrangement. Individual inflorescences are 10-16 mm in diameter, and consist of numerous pistillate florets densely packed around a receptacular core. Individual carpels are 2.7-3.6 mm long and 0.7-1.2 mm wide, and sometimes appear to be clustered, possibly in groups of five. Mature infructescences reach diameters of 16-19 mm, and bear elliptical achenes 3.7-6.5 mm long and 1.2-2.1 mm wide, which sometimes retain curved styles (Fig. 63).

Staminate inflorescences, which were assigned to Platananthus speirsae by Pigg and Stockey (1991), are globose, and borne on peduncles 7-10 mm long. Peduncles are spaced about 2-10 mm apart on long reproductive axes, in a subopposite to alternate arrangement. Individual inflorescences are 8.5-9.0 mm in diameter, and consist of numerous stamens densely packed around a receptacular core (Fig. 65). Perianth parts are obscure. Stamens are 2.2-2.5 mm long, with short filaments about 0.8 mm long, elongate pollen sacs up to

2.2 mm long and 0.25 mm wide. They were dispersed in groups and have long connectives that form a conical, caplike extension at the apex (Fig. 66). The pollen grains are tricolpate, prolate, and 18-22 μm in diameter, with reticulate ornamentation, and a tectate/columellate wall.

Platanaceous seedlings from Joffre Bridge Roadcut have suboppositely arranged, petiolate, ovate cotyledons. Laminae are about 5.2-7.5 mm long, with a maximum width of 5.4 mm. A few specimens show indications of actinodromous primary venation and reticulate higher-order venation. Young foliage leaves, where present, are helically arranged and exhibit characteristic platanaceous morphology, including serrate margins (Fig. 64). Venation is simple craspedodromous.

Occurrence: Several hundred specimens have been catalogued, including leaves; pistillate inflorescences; infructescences, some with mature achenes; staminate inflorescences and dispersed stamen groups, both with in situ pollen; and seedlings in several stages of development. Platanaceous remains are found primarily in the Channel-Fill Siltstone, Lower Lacustrine Sequence, and Mollusc Layer (Units 3 to 5). The seedlings are found in discrete lenses within the Channel-Fill Siltstone (Unit 3).

Discussion: The foliage and the globose, unisexual inflorescences from Joffre Bridge Roadcut resemble those of living Platanaceae (Boothroyd, 1930), but the inflorescences differ in size and mode of attachment (Pigg and Stockey, 1991). In living Platanus, the inflorescences are larger (around 20 mm in diameter), and there are one to several inflorescences per peduncle (Subgenus Platanus), or numerous inflorescence heads that are sessile on a reproductive axis (Subgenus Castaneophyllum). Extant Platanus carpels are clustered in groups of 5 to 9, and each bears a prominent ring of dispersal hairs that is lacking or not preserved in the Joffre Bridge material. In the staminate flowers of extant Platanus, the connectives are shorter than those seen at Joffre Bridge, and the stamens are shed individually rather than in groups (Manchester, 1986). The pollen from Joffre Bridge is consistent in size, ornamentation and wall structure with that of modern Platanus species.

Pigg and Stockey (1991) reconstructed a platanaceous plant, informally designated the Joffre plane tree, from the platanaceous remains at Joffre Bridge Roadcut, on the basis of their exclusive co-occurrence at this well-documented locality. Because the various organs are disarticulated and have not been found in organic connection, they were assigned to separate generic names, rather than to a single taxon. Pigg and Stockey (1991) assigned the leaves to Platanus nobilis Newberry, sensu Wolfe and Wehr (1987). The pistillate inflorescences and infructescences were assigned to the fossil genus Macginicarpa (Manchester, 1986) based on the size of the inflorescence head, the grouping of the carpels, the carpel shape, and the lack of dispersal hairs. Because they are consistently borne on long penduncles, and because the perianth parts are poorly known, Pigg and Stockey established the new species M. manchesteri for them. Similarly, they assigned the staminate inflorescences to the fossil genus Platananthus (Manchester, 1986), and they established the new species P. speirsae for them because of their long peduncles and fairly large inflorescence heads.

Platanoid leaves and reproductive structures first appear in sediments of Lower Cretaceous (Albian) age, and the known platanoid and platanaceous material from Upper Cretaceous and Tertiary assemblages exhibits a wide range of diversity (Manchester, 1986; Crane et al., 1993; Pedersen et al., 1994). Platanus is the only extant genus within the family Platanaceae, and it includes six or seven living species, all of which are trees (Cronquist, 1981; Ernst, 1963). They are found from Central America to Ontario, and from the eastern Mediterranean region through the Himalaya mountains to Southeast Asia (Cronquist, 1981; Ernst, 1963). Although the living Platanus species show less diversity than is seen in fossil platanoids (Pedersen et al., 1994), they still enjoy a fairly wide distribution today, in contrast to the living species of Cercidiphyllum, Metasequoia, Glyptostrobus and Ginkgo.

Depositional settings indicate that the fossil Platanaceae favored riparian and floodplain environments, just as living Platanus species do today (Cronquist, 1981; Manchester, 1986). The Joffre plane trees clearly did as well, shedding vegetative and reproductive structures into the fluvial, lacustrine and backswamp environments represented by the Channel-Fill Siltstone, Lower Lacustrine Sequence and Mollusc Layer (Units 3 to 5). The platanaceous seedlings illustrate the ability of this plant to colonize open areas and disturbed soils. Found among the more abundant seedlings of Joffrea (see discussion above) in lenses within the Channel-Fill Siltstone, the platanaceous seedlings appear to have been colonizing temporarily emergent shorelines or sandbars when they were buried in place.

Order URTICALES
Family ULMACEAE
Genus Chaetoptelea Liebmann
Chaetoptelea microphylla (Newberry) Hickey

(Plate 9 , Figs. 67-69)

Description: Leaf blades are narrow-ovate to lanceolate, and often slightly asymmetrical, 25-55 mm long and 7-15 mm wide, with a length-to-width ratio of 1.7-3.7 (Figs. 67, 69). Leaf apices are acute to long acuminate. Bases are obtuse, rounded to cordate, and sometimes asymmetrical. Petioles are short, usually 0.7-1.5 mm long. Leaf margins are toothed, with acuminate serrations, mostly of type D-1 (Hickey, 1973), usually with 1 or 2 subsidiary teeth on the basal side (Fig. 68). Venation is pinnate, simple craspedodromous. The primary vein is moderately thick and straight to curved. Secondary veins curve smoothly from the primary to the margin, diverging from the primary at angles of about 50-60°, spaced 0.9-4.0 mm apart. Secondaries often dichotomize near the margin. Intersecondaries are rare. Tertiaries depart at steep to right angles.

Occurrence: About 60 leaves have been collected from the Channel-Fill Siltstone and Lower Lacustrine Sequence (Units 3-4).

Discussion: The family Ulmaceae is divided into two subfamilies, Celtoideae and Ulmoideae, the latter of which is usually considered to include six or seven extant genera (Sweitzer, 1971; Manchester, 1989). Some investigators, including Sweitzer (1971) and Manchester (1989), have considered the genus Chaetoptelea Liebmann to be congeneric with Ulmus L. However, leaves and fruits assignable to Chaetoptelea have been recognized in a number of Tertiary fossil assemblages (e.g., Burnham, 1986; Hickey, 1977; MacGinitie, 1941), which may strengthen the case for its retention as a distinct genus. There is only one living species, C. mexicana Leibmann, a large tree which is found in Central America south of 22° lattitude.

Burnham (1986) studied the foliar morphology of fossil leaves of Subfamily Ulmoideae from western North America, using discriminant analysis. She found that the early Tertiary specimens conformed to the morphological ranges of three extant genera: Zelkova Spach, Chaetoptelea and Ulmus. She recognized two morphotypes within Chaetoptelea, designated Chaetoptelea A and

Chaetoptelea B, which were distinguished on the basis of tooth/sinus types and higher-order venation.

The ulmaceous leaves from Joffre Bridge Roadcut are consistent with Burnham's *Chaetoptelea* A, as are those described as *Chaetoptelea microphylla* by Hickey (1977). In addition to Hickey's specimens from the late Paleocene Golden Valley Formation of North Dakota, leaves of the *Chaetoptelea* A type are known from a number of late Paleocene to late Eocene localities in California, Oregon, Washington, Wyoming and Alaska (Burnham, 1986).

At Joffre Bridge Roadcut, leaves of *C. microphylla* are found mainly in the Channel-Fill Siltstone and Lower Lacustrine Sequence (Units 3-4), along with remains of *Joffrea* and *Platanus*, and samaras of *Deviacer*, suggesting that *Chaetoptelea* may have shared the riparian environment with those taxa.

Subclass DILLENIIDAE
Order SALICALES
Family SALICACEAE
Genus ? *Populus*
Populus penhallowi Bell
(Plate 11, Fig. 84)

Description: The leaves are ovate, reaching lengths of 4.5 - 8.5 mm and widths of 3.5 - 4.5 mm (Fig. 84). The lamina is thin and membranaceous. The margin is entire, the apex is acute, and the base is obtuse and decurrent. Petioles are not preserved on these specimens. The venation is brochidodromous. The primary vein is straight. The secondaries arise at angles of about 40-50°, curving to form loops near the margin. Higher order venation has not been preserved.

Occurrence: Eight specimens, most of which are fragmentary, have been recovered from the Concretion Zone (Unit 6a) of the Upper Lacustrine Sequence.

Discussion: These specimens are conspecific with a leaf from the Blindman River area that Penhallow (1902) referred to Populus ungeri Lesquereux. Bell (1949) noted that Penhallow's specimen differed from P. ungeri in both shape and venation, and he established the taxon P. penhallowi for it.

At both Joffre Bridge Roadcut and the mouth of the Blindman River, these leaves are preserved only as faint impressions in grey lacustrine mudstone. They appear to have been very delicate, with a membranaceous (Hickey, 1973, 1979) lamina, and must have been produced by a tree or shrub that grew near the margin of the lake.

Subclass ROSIDAE
Order SAPINDALES
Family SAPINDACEAE/ACERACEAE
Genus Deviacer Manchester
Deviacer sp.

(Plate 9 , Figs. 71, 72, 74)

Description: Fruits are schizocarpic samaras 1.5-2.4 mm long and 0.6-1.7 mm wide. None have been found in attachment, but scars indicate an attachment angle of about 30° to the trend of the wing (Fig. 71). Nutlets are symmetrical and elliptic, 0.3-0.7 mm long and 0.2-0.4 mm wide (Fig. 74). The distal edge of the wing is straight to gently convex, and strongly veined. The proximal margin is occasionally convex immediately distal to the nutlet (Figs. 71, 72), but is more commonly gently concave throughout its length. The wing apex is rounded. Veins are numerous, and the majority are coalesced along the distal margin of the wing. They dichotomize and anastomose toward the proximal margin.

Occurrence: About 50 samaras have been collected from the Channel-Fill Siltstone and Lower Lacustrine Sequence (Units 3-4).

Discussion: Wolfe and Tanai (1987) observed that some Paleocene and Eocene samaras that had been assigned to the genus Acer differ significantly from those of younger and modern Acer species in the venation of the wing. These samaras "have an attachment scar that is on the same side of the samara as are the coalesced veins of the wing; the strongly veined "back" of the wing is thus distal in these fruits, rather than proximal as in Acer" (Wolfe and Tanai, 1987). They felt that these fruits, and associated leaves that had been assigned to "Acer" arcticum Heer and "Ampelopsis" acerifolia (Newberry) Brown, were not valid Acer, and postulated that they might represent an extinct genus of Aceraceae which they termed the "Acer" arcticum complex. Wolfe examined some of the samaras from Joffre Bridge Roadcut and felt that they might represent a new species of the "Acer" arcticum complex (Wolfe, pers. comm.).

Manchester (1994) erected the genus Deviacer for samaras bearing the attachment scar on the dorsal margin of the nutlet, like those of Wolfe and Tanai's "Acer" arcticum complex, rather than on the ventral margin, as in true

Acer. Deviacer samaras have not been found in attachment, and it is not known whether they were borne in pairs as in the Aceraceae, or in threes as is typical in the Sapindaceae (Manchester, 1994; Wolfe and Tanai, 1987). Noting that the attachment angle indicates that the proximal or dorsal margins of Deviacer samaras would have faced each other, as is typical in extant samaroid Sapindaceae, Manchester placed Deviacer in the family Sapindaceae "sensu lato". He observed that although the family name Aceraceae is well established, some authors have concluded that "there is no firm basis for treating it separately from the Sapindaceae" (Manchester, 1994).

Manchester (1994) named one species from the Eocene Clarno Formation of Oregon, Deviacer wolfei. The samaras from Joffre Bridge Roadcut differ from D. wolfei in size and shape, and thus represent a new species of Deviacer. They also lack the prominent proximal keel and recurved "rudder-like projection" (Manchester, 1994) seen adjacent to the attachment scar in D. wolfei.

The Deviacer samaras from Joffre Bridge Roadcut are found in the sediments of the Channel-Fill Siltstone and Lower Lacustrine Sequence (Units 3 and 4), associated with remains of Joffrea and the platanaceous tree described above, and a few leaves of "Acer" arcticum (see discussion below). Many of the Deviacer samaras show signs of abrasion, and may have carried for some distance by the river system before being washed into the abandoned channel setting and preserved.

Family SAPINDACEAE/ACERACEAE

Genus Acer Linnaeus

"Acer" arcticum Heer

(Plate 9, Figs. 70, 73)

Description: The leaves are petiolate and shallowly three-lobed, 60-80 mm wide and approximately 65 mm long, with a truncate base; the apices are not preserved (Figs. 70, 73). The margin has obtuse crenate teeth and rounded sinus. The venation is actinodromous. The two lateral primaries diverge from the medial primary at or near the base, at angles of 30-45°. Three or four secondaries diverge from the outer side of the lateral primaries. The teritaries are alternate, and those between the medial and lateral primaries tend to form a V-shaped pattern pointing apically.

Occurrence: Five fragmentary leaves (S9,607; S12,027; S12,029; S12,060; S16,181) have been recovered from the Channel-Fill Siltstone and Lower Lacustrine Sequence (Units 3-4).

Discussion: These leaves are not common or well preserved at Joffre Bridge Roadcut, but appear to be consistent with "Acer" arcticum as described by Wolfe and Wehr (1987) and Wolfe and Tanai (1987). The leaves resemble those of extant Acer in their overall shape and architecture. However, Wolfe and Wehr (1987) and Wolfe and Tanai (1987) noted that the rounded teeth and sinuses are not found in extant species of Acer, and suggested that these leaves may not represent true members of that genus. The leaves are commonly associated with samaras of the Deviacer type (see discussion above), which strongly supports the hypothesis that they are not leaves of true

Acer (Wolfe and Wehr, 1987; Wolfe and Tanai, 1987), and a new generic name appears to be warranted for them.

Leaves of "*Acer*" *arcticum* closely resemble those of "*Ampelopsis*" *acerifolia* (Newberry) Brown (e.g., Hickey, 1977), with which they have been compared by Wolfe and Wehr (1987) and Wolfe and Tanai (1987), and it appears likely that the two taxa are closely related. The association between leaves with this morphology and *Deviacer* samaras lends support to their relationship with extant Sapindaceae or Aceraceae, rather than with extant *Ampelopsis* (Vitaceae).

At Joffre Bridge Roadcut, the "*Acer*" *arcticum* leaves are found in the same layers with the *Deviacer* samaras, and both organs may well have been produced by the same plant. It appears unlikely that the parent plant was common at Joffre Bridge Roadcut, however. The leaves are rare, and the few specimens are fragmentary and tattered, suggesting that they suffered a moderate distance of transport. The samaras are more common at the site, likely because they are more robust, but they, too, appear to have survived moderate transport.

Order GERANIALES
Family OXALIDACEAE
Genus *Averrhoites* Hickey
Averrhoites *affinis* (Newberry) Hickey

(Plate 10, Figs. 77, 78)

Description: Leaflets are asymmetrical, ovate, at least 120 mm long and 35 mm wide, with a length-to-width ratio of about 3.5 (Fig. 77). Leaf apices are acute, bases are acute to obtuse and asymmetrical, and margins are entire. Venation is pinnate, brochidodromous to eucamptodromous. Primary vein is straight to curved, and much thicker than the secondaries. Secondaries diverge at an angle of about 75°, curving upward toward the apex, sometimes arching and joining the superadjacent secondary (Fig. 78). Intersecondaries are common. Higher order venation not apparent on these specimens.

Occurrence: Eight specimens of detached leaflets, from the Channel-Fill Siltstone and Lower Lacustrine Sequence (Units 3-4).

Discussion: Pinnately compound leaves with this type of architecture were first assigned to Sapindus affinis and Sapindus membranaceous by Newberry (1898). Their assignment to Sapindus was questioned by a number of authors, and Hickey (1977), studying leaves from the Golden Valley Formation of North Dakota, concluded that the leaves more closely resembled those of extant Averrhoa carambola Linnaeus. Hickey erected the genus Averrhoites "for leaves whose architecture is similar to the modern genus Averrhoa", but noted that it was "not meant to indicate close taxonomic affinity".

The specimens of A. affinis from Joffre Bridge Roadcut are all detached leaflets, few of which are well preserved, but they resemble those described and illustrated by Hickey (1977). Specimens collected nearby around the mouth of the Blindman River are better preserved, and more clearly exhibit the secondary and tertiary venation that Hickey described. Leaflets of A. affinis have also been described from the Sentinel Butte Formation of North Dakota (Crane et al., 1990), and from the Ravenscrag Formation of Saskatchewan (McIver and Basinger, 1993).

At Joffre Bridge Roadcut, Averrhoites leaflets are rare. They are found in the Channel-Fill Siltstone and Lower Lacustrine Sequence (Units 3-4), among the more common remains of other woody dicots that inhabited riparian and floodplain environments, such as Joffrea and Platanus.

Subclass INCERTAE SEDIS

"Viburnum" cupanioides (Newberry) Brown

(Plate 10 , Figs. 75, 76)

Description: Leaf laminae are ovate to elliptic, 2.9-12.6 mm long, 1.5-8.5 mm wide, with a length-to-width ratio of 1.6-2.2 (Figs. 75, 76). Leaf apices are acute, obtuse or rounded. Bases are cordate, obtuse or rounded and often slightly asymmetrical. Petioles are missing from many of the specimens because they curve out of the plane of the leaf blade. Margins are entire in the basal 30-90% of the leaf, and toothed in remainder (Fig. 76). Teeth are serrate and obtuse, sinuses are angular to rounded. Venation is pinnate. The primary vein is straight and moderately thick. Secondaries are straight to gently curved, diverging from the primary at angles of 50°-60°, and often branching once, or occasionally twice. Most of the secondaries are craspedodromous, terminating in tooth apices; the basal 1-2 pairs of secondaries are camptodromous and terminate before reaching the entire portion of the margin. Tertiary veins are percurrent. Higher order veins and areolation are not well preserved.

Occurrence: At least 150 specimens of leaves and leaf fragments have been recovered. They are most common in the Concretion Zone (Unit 6a) at the base of the Upper Lacustrine Sequence, and occasionally are found in the Channel-Fill Siltstone and Lower Lacustrine Sequence (Units 3-4).

Discussion: Bell (1949) collected leaves of this type near the old Joffre Bridge (G.S.C. locality 3462), and near the mouth of the Blindman River. He assigned them to *Populus carneosa* (Newberry) Bell, which he based on *Phyllites carneosus* Newberry (1898), and he placed *Phyllites cupanioides* Newberry (1898) in synonymy. Brown (1962) reassigned those specimens and others from the Fort Union Group to the genus *Viburnum*, using the specific epithet of *P. cupanioides*.

Hickey (1977) described similar leaves from the Golden Valley Formation of North Dakota as "*Viburnum*" *cupanioides*, adding the quotation marks to indicate that he considered their assignment to *Viburnum* to be questionable. He stated that, based on the leaf morphology and venation, *Viburnum* is "a plausible generic assignment for this form, and is retained pending further study", but he also noted their resemblence to "some of the modern leaves of the genus *Hamamelis*". Other workers (e.g., Crane et al., 1990); S.L. Wing, pers. comm.) have also noted a similarity to some of the Hamamelidaceae, but the systematic relationship of these leaves remains uncertain at present.

The leaves from Joffre Bridge Roadcut conform very closely to the descriptions published by Bell (1949) and Hickey (1977), and thus are assigned to "*Viburnum*" *cupanioides*, sensu Hickey, retaining his caution about their affinity.

At Joffre Bridge Roadcut, the "*Viburnum*" leaves are common in the lacustrine sediments of the Concretion Zone (Unit 6a), which was deposited in very shallow water, near shore. *Joffrea* leaves, *Osmunda* pinnules, *Glyptostrobus* branches and cones, *Metasequoia* foliage, fragments of *Zingiberopsis* leaves, and the remains of a lilialean monocot, are also found in that unit.

Genus Wardiaphyllum Hickey

Wardiaphyllum daturaefolium (Ward) Hickey

(Plate 11 , Figs. 82, 83)

Description: Leaves simple, petiolate, ovate to wide elliptic, about 8.0-11.5 mm long, 5.0-8.0 mm wide, with a length-to-width ratio of about 1.5 (Fig. 82). Apices are acute to acuminate. Bases are rounded to truncate, decurrent along the petiole, and often slightly asymmetrical. Margins are entire below the basal secondaries, and in the apical 10-25% of the lamina, but are otherwise distinctively toothed. Teeth are prominent, sharp, narrow, and somewhat irregularly spaced (Fig. 83). Sinuses are rounded. The teeth often curve toward the apex, but their orientation varies, particularly for the basal teeth. Venation is pinnate, semicraspedrodromous. The primary vein is straight and unbranched. Secondaries diverge at angles of about 40°, forming loops by joining superadjacent secondaries at acute angles; the basal pair of secondaries may be downcurved if the base is truncate. Tertiary veins are percurrent, originating on both sides of the secondaries. Quaternary veins are orthogonal to tertiaries, forming pentagonal areoles. Quinternary veins branch once or twice, and have freely ending tips. A fimbrial vein is present.

Occurrence: About 20 leaves, mostly fragmentary, have been recovered from the Channel-Fill Siltstone and Lower Lacustrine Sequence (Units 3-4).

Discussion: Leaves with this morphology from Seven Mile Creek, Montana, were originally described and illustrated by Ward (1887) as ?Credneria daturaefolia. Cockerell (1908) discussed their resemblance to Populus. Bell (1949) collected similar leaves from the Paskapoo Formation near Rocky Mountain House, Alberta, and assigned them to Populus? daturaefolia (Ward)

Cockerell. Bell noted that, although there is resemblance to some species of Credneria and Populus, "the true taxonomic relationship of the species remains decidedly questionable". Brown (1962) agreed that "the identity of these leaves remains as doubtful as when Ward described them."

Hickey (1977) found that Ward's specimens differ greatly from the original generic description and illustration of Credneria Zenker, a taxon that was originally erected for Upper Cretaceous leaves from Germany. Hickey therefore erected the genus Wardiaphyllum, of uncertain affinity, for Ward's specimens. Hickey found "no convincing modern analogue" for these leaves, but noted some similarity to the Platanaceae in the proportions of the marginal teeth, and in the details of the tertiary and quaternary venation (Hickey, 1977). Until an association with fruits or other organs can be demonstrated, the affinity is likely to remain obscure.

The leaves from Joffre Bridge Roadcut closely resemble those described and illustrated by Ward (1887), Brown (1962) and Hickey (1977), and are thus assigned to Wardiaphyllum. These leaves are not common at Joffre Bridge Roadcut, but are occasionally found in the Channel-Fill Siltstone and Lower Lacustrine Sequence (Units 3-4), with the remains of woody dicots from riparian and floodplain environments, such as Joffrea and Platanus. Wardiaphyllum leaves have also been found at the Munce's Hill (One Jaw Gap) locality (Ti_4 age) near Joffre Bridge Roadcut.

Genus Fortuna McIver & Basinger

Fortuna marsilioides (Bell) McIver & Basinger

(Plate 11 , Figs. 85, 86)

Description: The leaves are very wide obovate, triangular; bilaterally symmetrical; 24-33 mm long, 28-34 mm wide, with a length-to-width ratio of 1:1; rounded apex; acute base; and no petiole (Fig. 85, 86). The margin is entire in the basal half, becoming toothed in the apical half; the teeth are obtuse and serrate, becoming dentate toward the apex. The venation is actinodromous, reticulate, basal (Fig. 86). There are eight primary veins; secondaries diverge at acute angles and become subparallel to the primaries; detailed venation features are poorly preserved.

Occurrence: Seven leaves have been recovered from the Upper Lacustrine Sequence, at the base of the Aquatic Plant Zone (Unit 6b).

Discussion: The Fortuna leaves from Joffre Bridge Roadcut resemble those described from the Upper Cretaceous (Maastrictian) St. Mary River Formation along the Oldman River north of Cowley, Alberta (Bell, 1949; McIver and Basinger, 1993); from the St. Mary River Formation on the east bank of the river across from the St. Mary Reservoir spillway (Stockey and Stockey, 1993); from the Paleocene Paskapoo Formation at the mouth of the Blindman River near Joffre Bridge Roadcut (McIver and Basinger, 1993); and from the Paleocene Ravenscrag Formation of Saskatchewan (McIver and Basinger, 1993).

Bell (1949) originally described specimens from the Oldman River locality as Antholithes (Nymphaeites?) marsilioides. McIver and Basinger (1993) named the genus Fortuna and presented an emended diagnosis based on better-preserved material from the Paleocene localities noted above. They reinterpreted its rosettes as four simple leaves, rather than as sepals or bracts of a flower as Bell had done. The leaves from Joffre Bridge Roadcut are detached.

Although the lateral margins of the leaves from Joffre Bridge Roadcut appear entire, like those from the Oldman River locality, this is probably the result of poor preservation, as McIver and Basinger (1993) suggest for some of their specimens. The Paleocene Fortuna leaves that they describe all reveal a toothed margin. Similarly, some of the best-preserved leaves from the St. Mary Reservoir Spillway locality exhibit small, delicate teeth along the lateral margins, but they are often covered by the surrounding matrix (Stockey, pers. comm.).

Although they are rare at the site, the Fortuna leaves from Joffre Bridge Roadcut support the interpretation of an aquatic or semi-aquatic habit for this plant (McIver and Basinger, 1993). They were found in a greenish grey lacustrine claystone (Unit 6b), associated with the remains of free-floating aquatic plants (Spirodela, Ricciopsis and Azolla), and fragments of lilialean leaves.

Unidentified Aquatic Leaf

(Plate 13 , Figs. 93, 94)

Description: None of the specimens are complete, but these leaves appear to be symmetrical and orbiculate (Figs. 93, 94), about 20 mm long and wide. The leaf lamina has a fairly delicate, membranaceous texture. Leaf apices are obtuse, and the bases are missing or very poorly preserved on these specimens. The margin is toothed. The teeth are regularly spaced, with rounded sinuses, convex sides, obtuse apices, and dark glandular tips of the chloranthoid type (having a medial vein "braced" by two prominent laterals which join it; Hickey and Wolfe, 1975). Venation appears to be palinactinodromous, with about 8-10 primary veins diverging from a point near the base, branching dichotomously about 3 times before terminating at the marginal glands. Secondaries diverge at acute to right angles and curve to run subparallel to the primaries, ultimately joining primaries or other secondaries to form a reticulate network. Tertiaries diverge at high angles, forming an orthogonal reticulate pattern. Quaternary veins are rarely preserved, but appear to diverge from the tertiaries at right angles and end freely within the rectangular areoles without curving or branching.

Occurrence: Ten fragmentary specimens of leaves have been recovered from the Upper Lacustrine Sequence, at the base of the Aquatic Plant Zone (Unit 6b).

Discussion: These leaves are rare at Joffre Bridge Roadcut, and were found at the base of the Aquatic Plant Zone, with remains of the Spirodela-like plant, Glyptostrobus twigs, and scattered Osmunda pinnules and fragments of Zingiberopsis leaves. This setting and their delicate texture suggest that they may have been the floating leaves of an aquatic plant. However, they are fragmentary and the leaf bases are missing or poorly preserved, so nothing is known about their mode of attachment. Given this limited evidence, it is not possible to draw any meaningful conclusions about the structure or affinities of their parent plant at present.

Unidentified Leaf 1

(Plate 10 , Figs. 80, 81)

Description: Two leaves, both fragmentary. Apices are not present, and shape and size are uncertain. Lamina is greater than 40 mm long and 30 mm wide. Base appears to have been cuneate (Fig. 81). A few small, rounded serrations are present on the margin (Fig. 80). Venation is acrodromous. About six primary veins diverge from the base, and most branch once near the base. Secondaries diverge at shallow angles and become subparallel to the primaries. Tertiaries diverge at nearly right angles. Higher order veins form a random reticulate network.

Occurrence: There are two fragmentary leaves preserved on a single slab (S16,943). Their exact stratigraphic position is not known, but the matrix is consistent with the Channel-Fill Siltstone or Lower Lacustrine Sequence (Units 3-4)

Unidentified Leaf 2

(Plate 10 , Fig. 79)

Description: A single fragment of a leaf, 28 mm long and 6mm wide, with an acute apex and entire margin (Fig. 79). Venation is brochidodromous. The primary is sinuous. The secondaries diverge alternately at high angles, sometimes branching once before joining supra-adjcaent secondaries or the fimbrial vein. Higher order venation is obscure.

Occurrence: One fragmentary leaf apex, S12,132, has been recognized. Its exact stratigraphic position is not known, but the matrix is consistent with the Channel-Fill Siltstone or Lower Lacustrine Sequence (Units 3-4).

Class LILIOPSIDA
Subclass ALISMATIDAE
Order ALISMATALES
Family ALISMATACEAE
Genus Alismaphyllites Knowlton
Alismaphyllites grandifolius (Penhallow) Brown

(Plate 15, Figs. 107, 108)

Description: The specimens are fragments of large leaves with entire margins (Figs. 107, 108). There are four subsets of parallel veins, designated A, B, C, and D in order of decreasing strength, which are regularly spaced and form the pattern ADCDBDCDA over an interval of 3-4 mm. The weak veins of the D subset are discontinuous, sometimes curving to join adjacent veins or transverse veins at acute to right angles. There are several subsets of discontinuous transverse veins that cross the parallel vein subsets at acute to right angles. The strongest reach lengths of up to 25 mm before terminating against veins of the A subset. The weakest extend only between D subset veins. Areoles range from quadrangular and polygonal to lenticular (Fig. 108).

Occurrence: About 10 fragmentary leaves have been recovered from the Concretion Zone (Unit 6a) and the base of the Aquatic Plant Zone (Unit 6b) in the Upper Lacustrine Sequence.

Discussion: These leaves appear to be conspecific with those described by Penhallow (1902) as Majanthemophyllum grandifolium. Penhallow's material came from outcrops near the mouth of the Blindman River, not far from Joffre Bridge Roadcut, where leaves of this kind are more common and much better preserved.

Berry (1926) and Bell (1949) referred additional material from the Paskapoo Formation to Majanthemophyllum, although Bell noted that the affinity of these leaves was uncertain and the assignment was questionable.

Brown (1962) observed that the tertiary venation excludes these leaves from the genus Majanthemophyllum (Liliaceae). Comparing them to leaves of some species of Alisma, Echinodorus, Aponogeton and Potamogeton, he referred them to Alismaphyllites (Alismataceae), and suggested that they might be related to the Miocene fossils Alisma macrophyllum Heer and Potamogeton nordenskioldii Heer from Spitzbergen (Heer, 1876).

The Alismaphyllites leaves from Joffre Bridge Roadcut are uncommon and fragmentary, and thus can add little to our understanding of the plant that bore them or its affinities, although further study of the material from the Blindman River area would likely be productive. Like those from the Blindman River, the specimens from Joffre Bridge Roadcut are found in lacustrine sediments, associated with the remains of Zingiberopsis and aquatic plants, a setting that is consistent with their having been produced by a plant that grew along the shore of the lake or in shallow water.

Subclass ARECIDAE

Order ARALES

Family ARACEAE

Spirodela-like monocot

(Plate 12 , Figs. 87-92)

Description: Each plant consists of a single orbiculate to very wide ovate leaf-like body with an entire margin (Figs. 87, 88), typically 15-20 mm in diameter but reaching a maximum of 40 mm. Dorsal and ventral surfaces are pubescent, with hairs 0.2-0.4 mm long. A node or centrum up to 3 mm in diameter is located in basal to central region (Figs. 88, 89). "Daughter" plants arise from two pouches adjacent to the centrum (Fig. 91). Venation is campylodromous (Fig. 87). Twelve to 14 curved primary veins radiate from the node, converging distally with a marginal vein. Numerous (usually about 25-30) simple, unbranched filiform rootlets, about 0.2 mm wide and up to about 15 mm long, radiate from the centrum beneath the dorsal surface. A single primary root up to 3 mm wide and 40 mm long, bearing filliform lateral rootlets, also issues from the node (Figs. 88, 89). A stolon about 3.5 mm wide, reaching lengths of more than 40 mm, is also connected at the node. The pollen is monoporate, with a circular polar outline, a subcircular to ovate equitorial outline, and a diameter of 20-25 μm (Fig. 90). The wall is 1.5 μm thick and consists of three layers: the foot layer and tectum are homogeneous and of equal thickness, separated by a very thin infratectal layer of granular material (Fig. 92). The sculpturing is echinate. The echinae are connate in shape, about 2.0 μm tall, and constricted at the base; the bases are convex at the inner surface of the tectum, but do not penetrate to the foot layer (Fig. 92). There is no evidence of an endexine (differentially staining layer).

Occurrence: More than 300 specimens have been recovered from a thin bed of claystone at the base of the Upper Lacustrine Sequence (Unit 6).

Discussion: This fossil shares many features with the extant genus Spirodela Schleiden: the single floating leaf-like body; the node or centrum from which the veins and roots originate; the two reproductive pouches adjacent to the centrum; the numerous unbranched filiform rootlets; and lemnaceous pollen morphology and ultrastructure. However, the plant body is much larger and more strongly pubescent than those of living Spirodela, and it posseses a large, branched primary root and a very long stolon. The branched root excludes this fossil from the genus Spirodela, and also from the family Lemnaceae, in which roots are filiform and unbranched, or absent (Hillman, 1961; den Hartog and van der Plas, 1970). It is therefore necessary to erect a new genus for this fossil, and despite its obviously close relationship to the Lemnaceae (as demonstrated by pollen morphology, for example), to place it in the family Araceae. Various fossils that have been assigned to Spirodela scutata Dawson share some, but not all, of the characters seen in this fossil from Joffre Bridge Roadcut, and thus although it is likely that they are closely related, they are not here placed in synonymy.

For more than 150 years, most botanists have held that the genus Spirodela was derived from the free-floating aroid Pistia L. by reduction (e.g., Schleiden, 1839; Engler, 1877; Arber, 1919, 1920; Maheshwari, 1958; Sculthorpe, 1967), and it is interesting that the branched root that excludes this fossil from the Lemnaceae resembles the roots seen in extant Pistia. It is therefore tempting to suggest that this fossil supports the traditional view. However, recent work on pollen morphology and ultrastructure (Landolt, 1986; Tarasevich, 1990; Grayum, 1990, 1992), and molecular studies (Duvall et al., 1993; Grayum, pers. comm.) indicate that the relationship between Spirodela and *Pistia* may not be as close as was previously believed, and the matter clearly merits further study.

Fossils resembling *Spirodela* and *Pistia* have been found in Alberta, Saskatchewan, Montana, Wyoming and North Dakota. *Pistia*-like forms first appear in strata of Upper Cretaceous age, and have been referred mainly to the taxon *Pistia corrugata* Lesquereux. *Spirodela*-like forms appear somewhat later, in lowermost Paleocene strata, and have been referred mainly to *Spirodela scutata* Dawson.

Unfortunately, there has been a moderate amount of confusion about the matter. Some of Dawson's specimens are not available, and Lesquereux's types included specimens of unrelated genera (Knowlton, 1900). A few authors (e.g., Lesquereux, 1878; Ward, 1887) argued that the two taxa were conspecific, while others (i.e., Brown, 1962; Krassilov, 1973) placed *Spirodela scutata* in synonymy with taxa that appear to be unrelated, as discussed below.

Most authors have concluded that *Spirodela scutata* and *Pistia corrugata* are distinct entities, however (e.g., Dawson, 1886; Berry, 1935; McIver and Basinger, 1993), and those names continue to be used. *Pistia corrugata* includes obovate, pubescent leaves with acrodromous venation, like those of extant *Pistia*; and *Spirodela scutata* includes orbiculate to reniform thalli with numerous rootlets and campylodromous venation. The fossils assigned to *Spirodela scutata* differ significantly from extant *Spirodela*, however, and their assignment to the living genus is questionable (Hickey, 1977; McIver and Basinger, 1993).

Spirodela scutata was first described from Wood Mountain, Saskatchewan, as Lemna (Spirodela) scutata by Dawson (1875). Dawson (1875, 1886) described the plant bodies as round or "kidney-form" to tri-lobed, up to one inch in diameter, with entire or slightly undulate margins, and numerous filiform roots "proceeding from a round spot" near the margin. He described the venation as "veinless or with very faint veins" radiating from "marginal or submarginal thickened spot" (Dawson, 1886). His plates show plants with unbranched rootlets radiating from a node, and a plant bearing two attached daughter plants. Significantly, branched roots that resemble the primary root of the Joffre Bridge plant were apparently associated with, but not attached to, one of the specimens that Dawson (1875) illustrated. Dawson (1875) described them as "roots with pinnate or radiating rootlets ... which are very common in these beds". It thus appears possible that a branched root may have been part of Dawson's plant, but the evidence is not conclusive.

Lesquereux (1878) referred two specimens from Point of Rocks, Montana, to Lemna scutata Dawson, and then proceeded to argue that L. scutata was conspecific with Pistia corrugata, which he described from the same locality. He argued that the material should be referred to the genus Pistia because of the "radicles, coming out in bundles from linear rootlets". However, none of Lesquereux's specimens proved to resemble Dawson's (Knowlton, 1900).

Ward (1886, 1887) referred specimens from Burn's Ranch, Montana to Lemna scutata and illustrated their venation, including the marginal vein. Ward's illustrations show a branched root that may be attached to one of the plants, but again the evidence is not conclusive.

Berry (1935) reviewed Dawson's and Lesquereux's work, and concluded that the two taxa are "perfectly distinct" entities. He noted that the use of the name *Lemna* should be dropped in favor of *Spirodela*.

Bell (1949) assigned specimens of Paleocene age from Alberta to *Spirodela scutata*, and reexamined Dawson's specimens. He described the venation, pubescence, and the imprint of "nearly equidimensional cell-like areas that may represent aerenchymatous tissue", and like Dawson (1875), he commented on the branched root, a "primary root or stem, 1 to 1.5 mm wide, [that] is also commonly associated with the plant body as if attached at its axial node."

Brown (1962) placed *Spirodela scutata* in synonomy with *Hydromystria expansa* (Heer) Hantke, along with several other taxa (*Hiraea expansa* Heer, *Nymphaeites brownii* Dorf, and *Carpites verrucosus* Lesquereux). He described the leaves as "sessile, or nearly so at nodes on a succulent prostrate stem or runner", and the roots only as "feathery rootlets [which] may sometimes be seen at the nodes". Brown added that he did not consider the assignment to be "completely appropriate" because the specimens clearly lack petioles, and it was not adopted by subsequent authors.

Krassilov (1973) proposed the name *Limnobiophyllum* Krassilov for "the leaves previously described from the Cretaceous-Paleocene of North America as *Lemna* (*Spirodela*), *Nymphaeites*, *Carpolithes* [sic] and *Hydromystria*", and he placed the material of Dawson (1875), Dorf (1942), Bell (1949), and Brown (1962) in synonymy with *Limnobiophyllum scutatum* (Dawson) Krassilov. Krassilov appears to have based his diagnosis largely on specimens from the Amur region of Siberia. Described as reniform leaves densely covered with "cylindrical protuberances" 0.2 mm in diameter, 0.3 mm high, and "notched at the apex", there is no evidence of pubescence, venation or roots in Krassilov's diagnosis and illustrations, and thus his material could not be conspecific with Spirodela scutata.

Chandrasekharam (1972, 1974) described ten specimens from the Genesee locality in central Alberta, and assigned them to Spirodela scutata, describing their venation, pubescence, and possible aerenchyma. The Genesee specimens were examined during the preparation of this thesis, and small unbranched rootlets can be seen attached to the centrum of some of the specimens. Branched roots, much smaller and more delicate than those of the Joffre Bridge plant, lie near a few of the specimens but are not attached (i.e., UAPC-ALTA S1534), and again it is not clear whether they were actually part of the plant.

Hickey (1977) described an "unidentified aquatic plant" from the Golden Valley Formation in North Dakota that exhibits many of the features of the Joffre Bridge plant: an orbicular, pubescent leaf-like thallus with two daughter thalli attached, and filiform rootlets radiating from a centrum along with a much longer and stouter primary root or stem. Because the venation was not discernable, Hickey declined to make a more certain identification. He noted, however, that the assignment of the fossil forms to the modern genera Lemna and Spirodela was inappropriate.

McIver and Basinger (1993) also observed that the fossil forms differ from extant Spirodela, citing their larger size, shape and coarse pubescence. They referred 15 specimens from Ravenscrag Butte, Saskatchewan, to Spirodela scutata and presented an emended diagnosis. The specimens from Ravenscrag Butte, like those from Genesee, lack evidence of a branched root. They were preserved in lacustrine clay, along with other aquatic plants, including one that was referred to Pistia corrugata by McIver and Basinger (1993).

The Joffre Bridge plant resembles Dawson's (1875, 1886) description of *Spirodela scutata* in its general shape and filiform rootlets that radiate from the centrum. It also produced daughter plants from two pouches adjacent to the centrum, as Dawson's plant appears to have done. Its venation closely resembles that described and/or illustrated for *Spirodela scutata* by Dawson (1886), Ward (1886, 1887), Bell (1949), Chandrasekharam (1972, 1974) and McIver and Basinger (1993). However, it is clearly distinguished from *Spirodela scutata* and from extant *Spirodela* by the long, stout, branched primary root that is attached at its centrum. It also appears to have reached larger sizes and been more robust than *Spirodela scutata*. The Joffre Bridge plant most closely resembles Hickey's (1977) "unidentified aquatic plant", which appears to possess a similar stout primary root, as well as two attached daughter plants, and it is unfortunate that venation is not discernable on that specimen.

The Joffre Bridge plant appears to have lived much like the Lemnaceae of today. Modern Lemnaceae float on or just below the surface of quiet bodies of fresh water, and are often found with *Riccia* and *Azolla* in quiet ponds and ditches (Landolt, 1986; Hillman, 1961). Driven by winds, the plants can accumulate along shorelines or on mudflats, sometimes piling up to thicknesses of several centimetres (Clark, 1979). The deposit at Joffre Bridge Roadcut probably records such an occurrence. Remains of the *Spirodela*-like plant are very abundant in a thin layer at the base of the Upper Lacustrine Sequence, along with occasional *Ricciopsis* thalli, scattered *Osmunda* pinnules and a few dicot leaves. The plants likely had become concentrated and stranded along the shore of the oxbow lake, where they became covered by fine clay and thus were preserved.

Although flowering is rare in living *Spirodela* (Schleiden, 1839; Saeger, 1929; Landolt, 1957), lemnaceous pollen, some of it in anther-like clumps, is abundant in the sediments that include these fossils, and in at least one case the remains of two anthers appear to be attached to a plant. The pollen resembles that of living Lemnaceae (Erdtman, 1952; Landolt, 1986; Tarasevich, 1990) in its size, shape, ornamentation, and single pore, differing only in the well-developed annulus surrounding the pore (Fig. 90), and the poorly developed collumellate layer that is represented only by a thin layer of granular material (Fig. 92).

The size, shape, ornamentation, and the single annulate pore of the pollen from this fossil strongly resemble those described in the fossil pollen genus Pandaniidites Elsik (Hotton et al., 1994). The fossil differs only in the thin infratectal layer, which consists only of granular material rather than "irregular granules to short collumellae" (Hotton et al., 1994) in Pandaniidites, and in the lack of thickening or depression of the exine beneath the echinae as reported for Pandaniidites by Jarzen (1983) and Hotton et al. (1994). Jarzen (1983), Hotton et al. (1994) and others have argued that Pandaniidites was produced by a plant with pandanaceous affinities, as its name implies, and have used its occurrence in the late Maastrictian and Paleocene sediments of mid-continental North America to support the interpretation that a tropical to subtropical climate prevailed across the Cretaceous-Tertiary boundary. Sweet (1986 and pers. comm.) has argued for a lemnaceous affinity, which would not imply a frost-free climate. The material from Joffre Bridge Roadcut lends strong support to Sweet's hypothesis, and the affinity of Pandaniidites, like the phylogeny of the Lemnaceae, clearly merits further study in light of this new evidence.

Subclass ZINGIBERIDAE
Order ZINGIBERALES
Family ZINGIBERACEAE
Genus Zingiberopsis Hickey
Zingiberopsis attenuata Hickey & Peterson

(Plate 15, Figs. 109, 110)

Description: The specimens are fragments of large leaves with entire margins. The venation includes a midrib or costa about 10 mm wide, which consists of about 12 separate parallel strands. A set of numerous parallel veins diverges from the costa at shallow angles, and consists of three discrete subsets of veins, designated the B, C and d subsets in order of decreasing strength by Hickey and Peterson (1978). The veins are arranged according to the pattern BdCdB and are regularly spaced about 0.2 mm apart. A set of transverse veins connects adjacent parallel veins. Transverse veins are straight to slightly sigmoidal, spaced 0.5-1.2 mm apart, and are perpendicular to oblique to the parallel vein set.

Occurrence: About 12 specimens of leaf fragments have been recovered from the Concretion Zone (Unit 6a) and the base of the Aquatic Plant Zone (Unit 6b) in the Upper Lacustrine Sequence.

Discussion: These specimens are fragmentary, but clearly exhibit features that are consistent with Zingiberopsis attenuata: a costa composed of individual strands; sets of numerous, closely spaced parallel veins of three strengths that diverge from the costa at a low angle; and transverse veins that are often oblique to the parallel veins.

More complete specimens of leaves of this taxon have long been known from localities near the mouth of the Blindman River. They were first described as a "dubious species" by Penhallow (1902). Bell (1949) described them as Cannophyllites magnifolia (Knowlton) Bell. Hickey and Peterson (1978) noted that, although the features of these leaves fall within the very generalized definition of Cannophyllites Brongniart, that name is preoccupied by a Carboniferous seed fern and thus is inappropriate. They assigned the specimens from the Blindman River area to Zingiberopsis attenuata, a new species of the genus Zingiberopsis which Hickey (1977) had erected based on material from the Golden Valley Formation of North Dakota.

The phylogeny and fossil record of the Zingiberales have been reviewed by Kress (1990). The venation of Zingiberopsis is similar to that of certain members of the Zingiberaceae, although the lack of evidence of a ligule (Tomlinson, 1969) casts some doubt on this affinity, as does the possible orientation of the epidermal cell walls (Daghlian, pers. comm.).

At Joffre Bridge Roadcut, the Zingiberopsis material is found in the shallow-water sediments at the base of the Upper Lacustrine Sequence, suggesting that the plant grew near the margins of the lake. Associated taxa include forms that grew rooted in shallow water (the lilialean plant and Fortuna), and free-floating plants that had accumulated near the lake margin (the Spirodela-like plant and Ricciopsis), as well as leaves of other members of the lakeshore plant community ("Viburnum", Glyptostrobus, Metasequoia, and Osmunda).

Subclass INCERTAE SEDIS

Lilialean Monocot

(Plate 14 , Figs. 101-103, 112)

Description: The leaves are preserved only as fragments. The lamina is typically 15-50 mm wide, with parallel sides (Fig. 103), and was probably ensiform; the total length is not known. The margin is entire. The venation is parallel and appears to consist of three sets, here designated the A, B and C sets in order of decreasing strength. The veins are commonly arranged according to the pattern ACCBCCA, although there is some variation. The strong veins of set A are generally spaced 1.0-1.2 mm apart, although the spacing decreases near the margin. No crossveins can be discerned.

One specimen shows the leaves apparently emerging from a rhizome (Figs. 101, 102). The rhizome is about 55 mm long and about 30 mm high, and is densely covered by round root-scars. Nearly 20 roots, still attached to the rhizome, are 3 mm wide and in excess of 70 mm long.

Occurrence: Fragments of these leaves are very common near the base of the Upper Lacustrine Sequence, in the Concretion Zone (Unit 6a) and the lower part of the Aquatic Plant Zone (Unit 6b). The specimen showing the leaves associated with a rhizome was recovered from the Concretion Zone.

Discussion: The affinity of this plant is uncertain. The lack of crossveins excludes the leaves from the genus Typha, with which long, linear leaves are often compared. The shape of the leaves, their venation, and the associated rhizome with its round root-scars and long roots, are more comparable to those of some of the Liliales. The extant Liliales include many perennial herbs from rhizomes, bulbs or corms, which have narrow, parallel veined leaves with open, sheathing bases (Cronquist, 1981).

Heer (1870) described the fossil Iris latifolia from the Miocene sediments of Spitzbergen as having leaves with similar shape and venation, and a rhizome with round root-scars and long roots. However, the rhizome of Heer's plant shows some evidence of segmentation in his illustrations, an observation that was confirmed by R.A. Stockey who examined Heer's specimens of Iris latifolia in 1995 (Stockey, pers. comm.). There is no evidence of segmentation in the rhizome of the plant from Joffre Bridge Roadcut.

Its occurrence near the base of the Upper Lacustrine Sequence indicates that this monocot grew rooted in very shallow water at the edge of the oxbow lake. It is associated with the remains of Glyptostrobus, Metasequoia, "Viburnum", Joffrea, Osmunda, and Zingiberopsis.

Class INCERTAE SEDIS
Unidentified Seed or Fruit

(Plate 13, Figs. 97, 98)

Description: The body is oribculate to reniform, 8.0-12.0 mm in diameter, reaching thicknesses of up to about 1.0 mm. The margin is a smooth, continuous rim about 0.2-0.3 mm wide, broken by a single notch or sinus up to 0.5 mm deep and wide (Figs 97, 98). The surface ornamentation consists of irregular, lenticular protrusions about 0.1 mm wide and up to 2.5 mm long, that radiate away from the sinus. Fragments of carbonaceous material adhere to the surface of some of the specimens.

Occurrence: About 45 specimens have been collected from the Channel-Fill Siltstone and Lower Lacustrine Sequence (Units 3-4).

Discussion: The shape and thickness of these bodies, with their distinct rim, notch, ornamentation, and carbonaceous coating, suggests that they were fairly robust, woody seeds or fruits, as does the absence of any trace of venation, attachment, or roots. They are found among the remains of Joffrea and other riparian taxa, suggesting that they may have been produced by a riparian plant.

These fossils show some resemblance to the taxon Porosia verrucosa (Lesquereux) Hickey (Araceae), which has a similar size, shape, and rim (e.g., Hickey, 1977; Crane et al., 1990; McIver and Basinger, 1993). In Porosia, however, the body is "composed of a carbonaceous groundmass, permeated with tubules oriented at right angles to the surface" (Hickey, 1977), which produce a distinctive surface texture quite different from the lenticular protrusions seen on the specimens from Joffre Bridge Roadcut. Porosia verrucosa is known from the Blindman River area near Joffre Bridge Roadcut, and permineralized specimens of P. verrucosa have been recovered from ironstones of Maastrictian age near Drumheller, Alberta (Fig. 5 of Aulenback and Braman, 1991; R. Serbet, pers. comm.). The latter specimens are currently under study by Serbet, and the results of that work may have implications for the specimens from Joffre Bridge Roadcut, as well as for P. verrucosa.

Striated Seed

(Plate 15 , Fig. 112)

Description: Ellipsoidal to oblong seeds, often curved, 3.0-4.2 mm long and 1.0-1.8 mm wide, with rounded or occasionally acute ends. The surface is covered by thin, parallel striations, and remains of carbonaceous material (Fig. 112).

Occurrence: More than 75 specimens have been catalogued from the Channel-Fill Siltstone and Lower Lacustrine Sequence (Units 3-4).

Cone-like Infructescence

(Plate 13, Figs.95, 96)

Description: Globose or subglobose infructescesces about 20 mm in diameter, consisting of clusters of obovate, coalified strucutres. Those structures are obovate in shape, 7-10 mrn in length and 3-5 mm wide (Figs. 95, 96), and may represent fruits, or bracts that subtended fruits or seeds.

Occurrence: About 20 specimens, mostly of isolated bracts or fruits, have been recovered from the Concretion Zone (Unit 6a).

Unidentified Branching Aquatic Plant

(Plate 13, Figs. 99, 100)

Description: Linear, parallel-sided axes 0.5-2.0 mm wide that branch dichotomously up to 4 times, and reach lengths of greater than 60 mm (Fig. 100), sometimes radiating in a whorl from the remains of an axis (Fig. 99).

Occurrence: About 30 specimens have been collected from the Concretion Zone (Unit 6a) in the Upper Lacustrine Sequence.

Unidentified Sheathing Structures

(Plate 14, Figs. 104-106)

Description: The structures are 1-4 mm wide, and lengths of up to 75 mm have been found. They are usually curved, sometimes strongly. Round to elliptical scars that may indicate vascular bundles (Rothwell, pers. comm.) give the structures a segmented appearance (Figs. 104, 106). In a few specimens (e.g., S17,079A/B, S16,690, S16,680), the structures are tightly curved around one another, and appear to represent the bases of clasping leaves with opposite phyllotaxis; axillary buds are present on a few of the specimens (Fig. 104) (Rothwell, pers. comm.). None of the specimens shows any discernable thickness; that is, they do not appear to penetrate vertically through the surrounding sediment.

Occurrence: About 25 specimens have been recovered from the base of the Concretion Zone (Unit 6a).

CHAPTER 5

CONCLUSIONS

Joffre Bridge Roadcut is becoming one of the best documented middle Paleocene fossil localities in North America due to long-term efforts by geologists and paleontologists. The age of the strata has been well established; the environments of deposition of the sediments and fossils have been documented in detail; a very large number of specimens has been recovered; and most of the floral and faunal remains have now been studied and described.

A well-established age is of fundamental importance, because it allows the flora and fauna to be compared with those from other sites of similar age throughout the world. In the case of Joffre Bridge Roadcut and neighboring sites in the Red Deer Valley area, this was accomplished through the integration of faunal succession, palynostratigraphic and magnetostratigraphic data in the years immediately before this thesis was undertaken.

The strata at Joffre Bridge Roadcut were exposed where possible and examined in detail during this thesis. The succession of strata was found to record the abandonment of a river channel and its development into an oxbow lake. The assemblages of plant remains showed a clear relationship to sediment type and environment of deposition, which reflects changes in the plant community itself as the local ecosystem changed, as well as changes in the taphonomic processes that were operative.

The benefits of collecting large amounts of material from a site became apparent during the systematic studies done for this thesis. The more common plants are known from hundreds of specimens, which has allowed them to be reconstructed with a high degree of confidence, including the range of morphology of some of their organs. This has led to an improved understanding of the plants and their phylogeny, both for newly recognized taxa such as the Spirodela-like plant, and for those that are generally considered to have been fairly common in central Alberta during the middle Paleocene, such as the taxodiaceous, cercidiphyllaceous and platanaceous taxa. Although the plants that were not commonly preserved at the site, such as "Acer" arcticum and Populus penhallowi, are still poorly known, being represented by only a few specimens, they would likely have remained entirely undetected if a lesser effort had been made. Faunal remains have come to light along with the plant remains and have been studied by others, further increasing our understanding of the middle Paleocene ecosystems of Joffre Bridge Roadcut.

Large numbers of specimens have also been recovered from the Blindman River sites and Munce's Hill in the Red Deer Valley area, and it is recommended that similar studies of the plant remains and their geological settings be conducted for those sites. The strata at those sites are similar in age to those at Joffre Bridge Roadcut, and preliminary examination of the available material indicates that different paleoenvironments are represented, additional taxa are present, and their state of preservation is very good. Information from those sites would add significantly to our understanding of the species diversity, climate, and ecosystems that existed in central Alberta during the middle Paleocene.

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PLATES

PLATE 1

Figure 1. The Crossbedded Sandstone (Unit 7) is the youngest Paleocene stratigraphic unit preserved at Joffre Bridge Roadcut. It likely represents a crevasse splay that prograded into the oxbow lake.

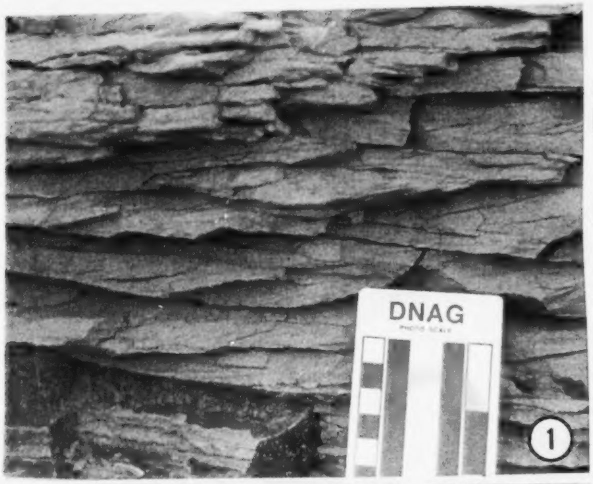
Figure 2. Joffre Bridge Roadcut, looking east, during trenching in August, 1993. The position of the Crossbedded Sandstone (#7) above the excavating equipment, the Mollusc Layer (#5) below the equipment, and the Lower Level Vertebrate Bed (#1) in the ditch near the road sign, are shown by arrows.

Figure 3. The beds of the Upper Lacustrine Sequence (Unit 6), overlying the darker coloured Mollusc Layer (Unit 5) (arrow). The overlying Crossbedded Sandstone was removed during the recovery of fish fossils from the top of the Upper Lacustrine Sequence.

Figure 4. Fossil molluscs, seeds and Metasequoia foliage preserved on a bedding surface from the Mollusc Layer. S38,514. X 1.4.

Figure 5. Large-scale crossbedding in the Fluvial Channel Sandstone (Unit 2) is exposed along the cliffs to the north, directly across the Red Deer River from Joffre Bridge Roadcut.

Figure 6. Rip-up clasts and the fragmentary remains of a leaf from the Fluvial Channel Sandstone. S39,350. X 1.0.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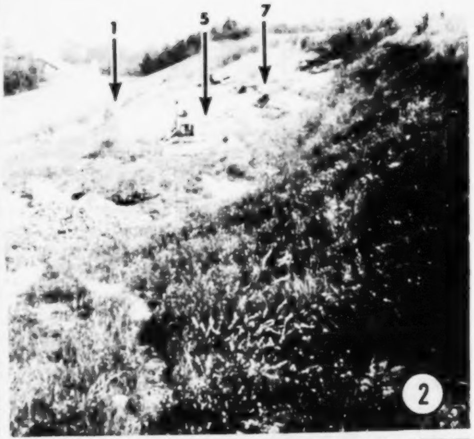
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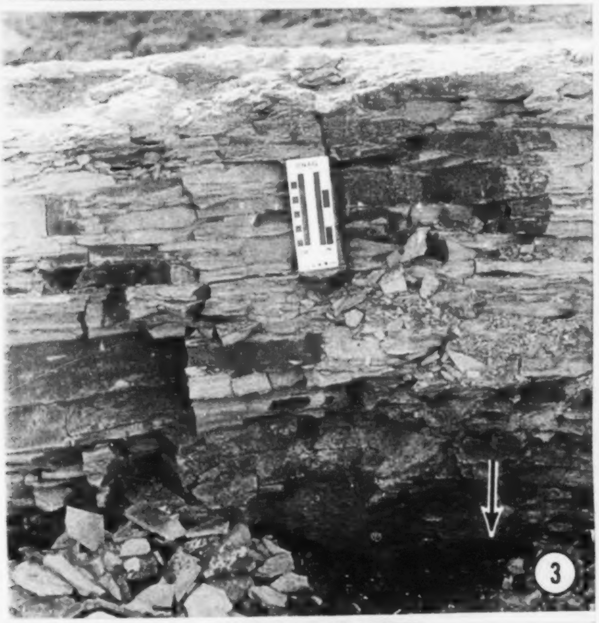
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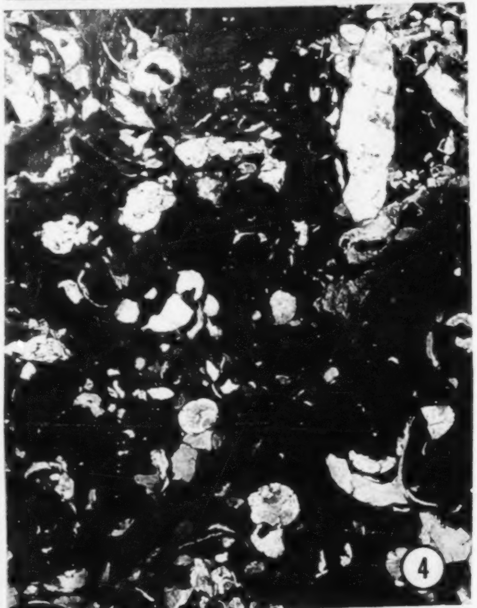
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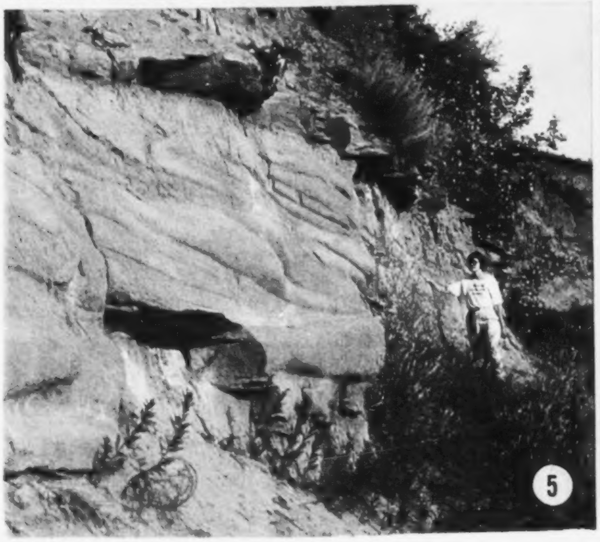
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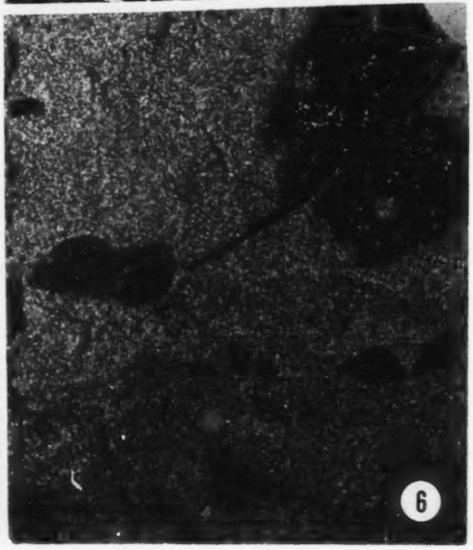
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PLATE 2

Figure 7-10. Ricciopsis Lundblad sp.

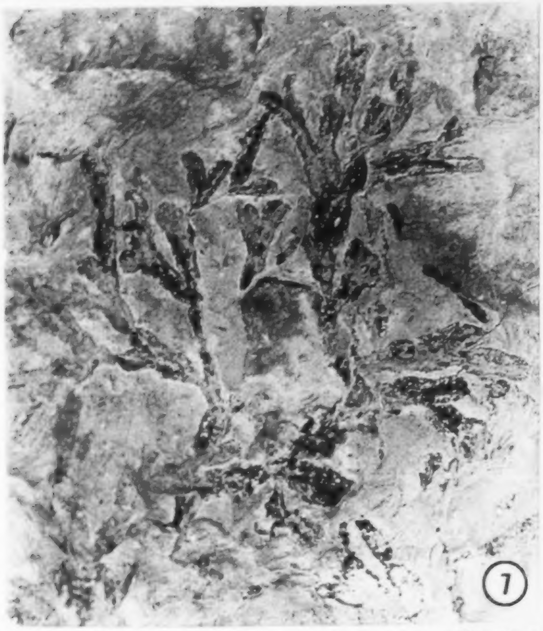
7. Thallus with the form of a loose, incomplete rosette. Note dilated regions and dichotomous branching. S17,062B. X 2.0.
8. The dilated region (D) of a thallus. Note the dorsal sulcus (S). The dark material is the remains of cuticle. S17,062B. X 3.5.
9. A thallus with dilated (D) and constricted (C) regions, dorsal sulcus, and remains of cuticle. S11,306. X 3.0.
10. A distinct dorsal sulcus (S). Note the branched, ribbon-like form of the thallus, and the adhering cuticle. S16,332a. X 6.5.

Figure 11. Muscites Brongniart sp.

11. Gametophyte with leaves (arrows). S12,519. X 3.6.

Figure 12-13. Equisetum L. sp.

12. A whorl of partially fused leaves. S9,252. X 4.2.
13. An axis, showing longitudinal ridges and furrows. S11,597. X 5.0.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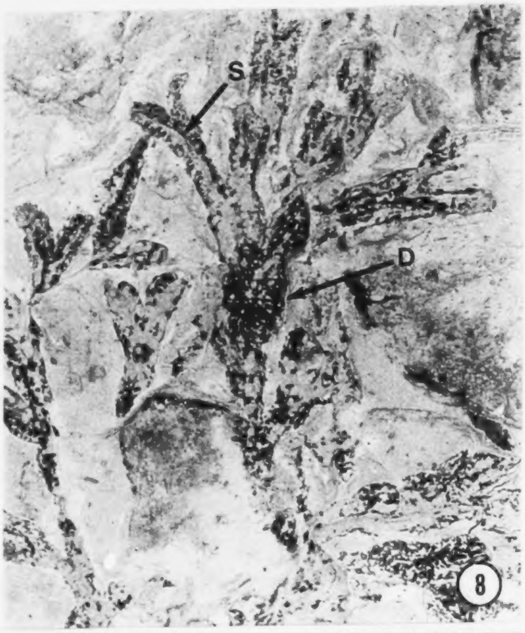
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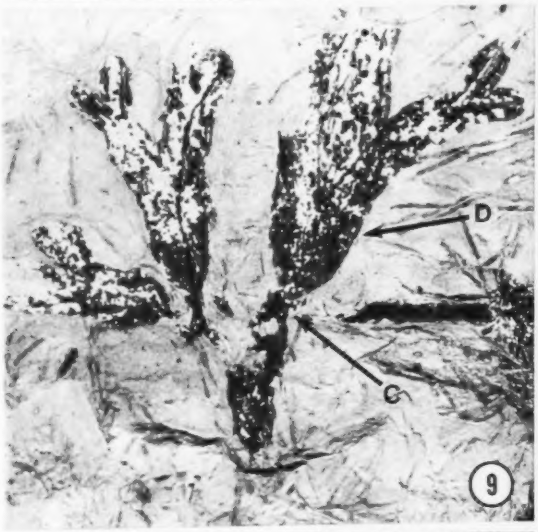
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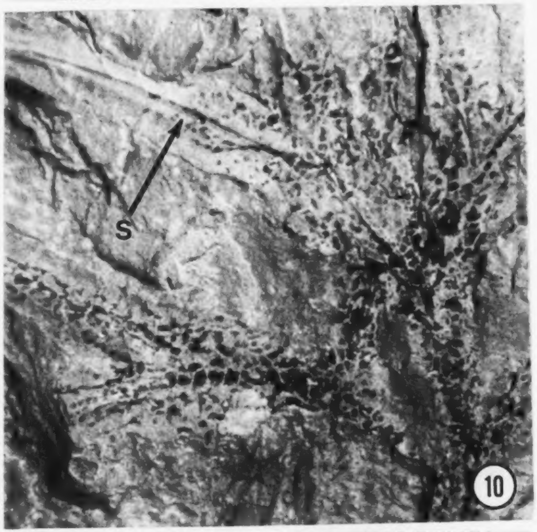
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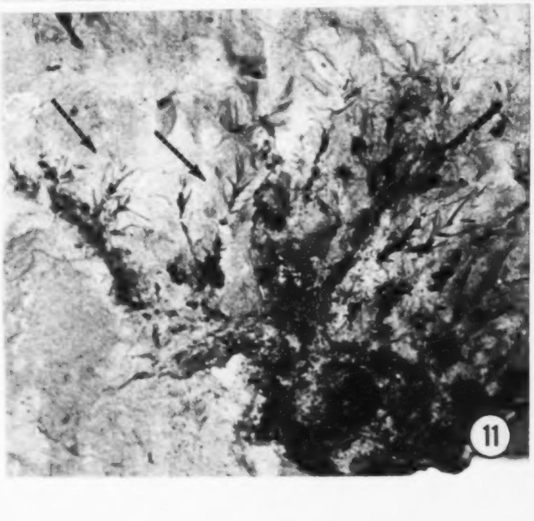
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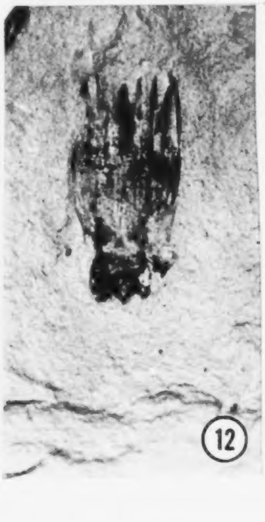
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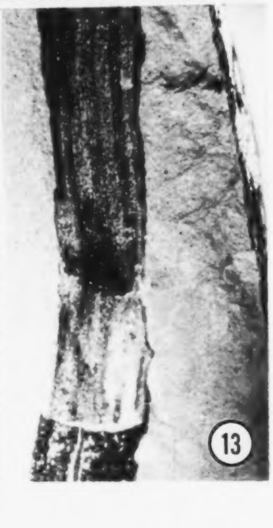
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PLATE 3

Figure 14-16. _Osmunda_ _macrophylla_ Penhallow.

14. Pinnules. Note serrate margin, midvein, and open dichotomous venation. S16,970A. X 2.8.

15. Rachis with alternately arranged pinnules. S16,970A. X 1.5.

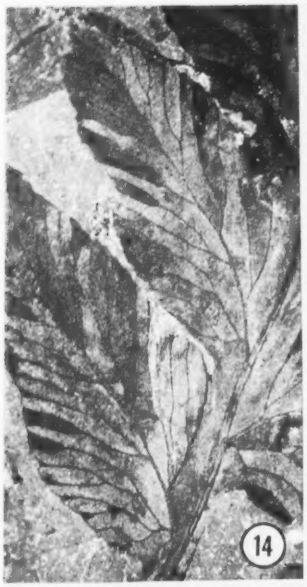
16. Detached pinnule. S16,948B. X 3.2.

Figure 17-19. _Dennstaedtia_ _blomstrandii_ (Heer) Hollick.

17. Rachis with alternately arranged pinnules. S16,950. X 1.8.

18. Rachis with alternately arranged pinnules. S16,951. X 1.4.

19. Pinnules with serrate margin and open dichotomous venation. S16,951. X 4.8.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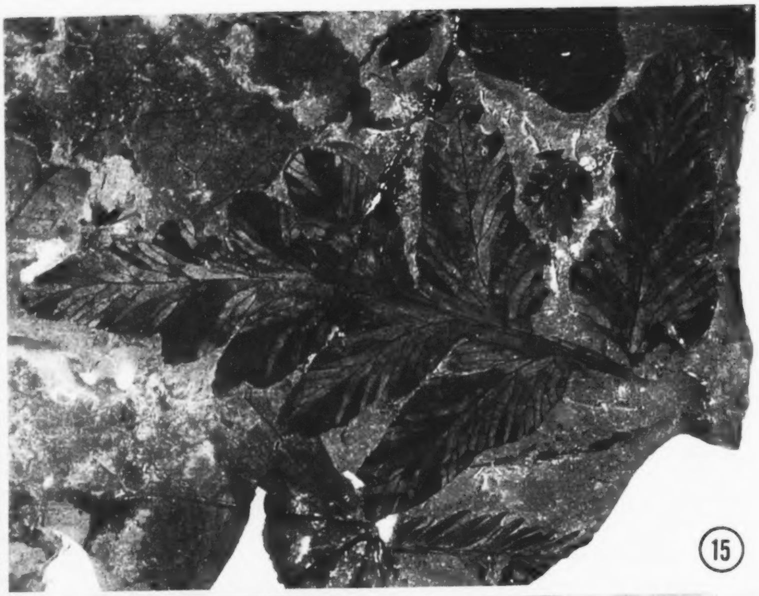
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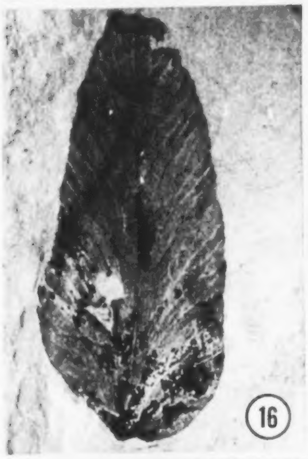
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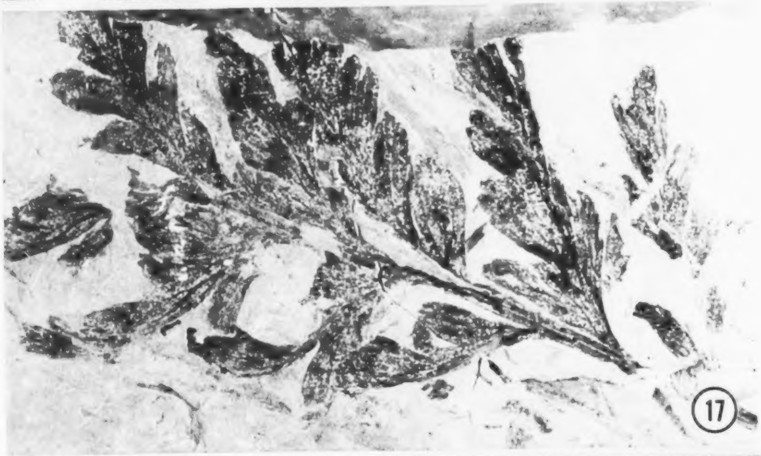
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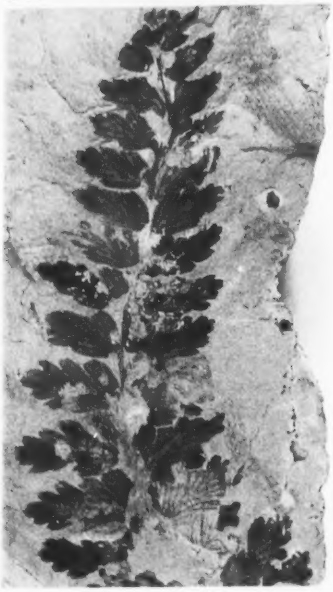
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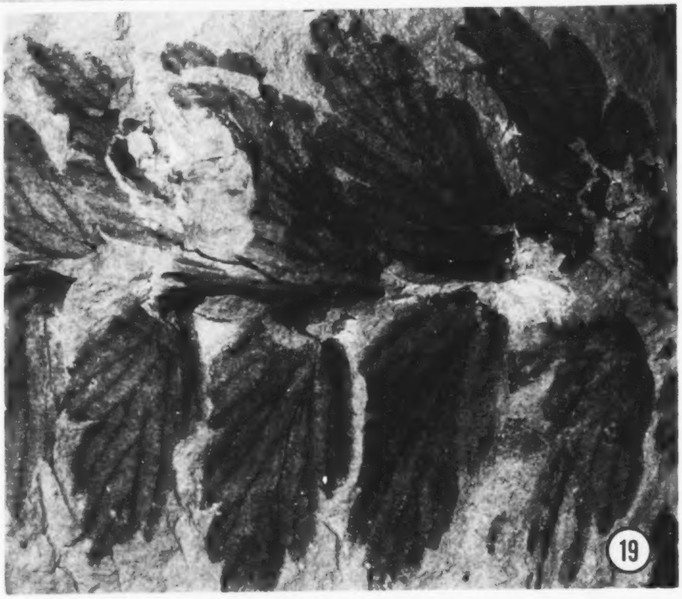
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PLATE 4

Figure 20-33. Azolla stanleyi Jain & Hall.

20. Vegetative sporophyte with crowded, imbricate leaves. S13,349. X 4.0.

21. Fertile sporophyte, with alternately arranged lateral branches. Arrows indicate megaspores. S13,350. X 4.0.

22. Pair of megaspores (arrows) in growth position on sporophyll (S). Note papillate texture of sporophyll. S13,644. X 300.

23. Megaspore complex showing floats (arrows) within the supraspore. X 170.

24. Megaspore with most of the filosum and outermost floats removed. Note conical shape of innermost floats (arrows) held in place by filaments of the filosum. X 180.

25. Filosum filaments. X 2300.

26. Experine surface. X 900.

27. TEM cross-section of megaspore wall showing wall layers: exine (e), inperine (i), experine (o), and filosum (f). X 3600.

28. Massula attached to the filosum of a megaspore complex. Note fluke-tipped glochidia (arrows) projecting from massula surface. X 350.

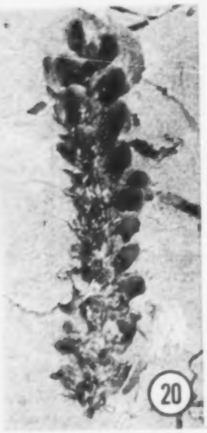
29. Massula attached to a megaspore complex. Massula surface has broken down, exposing microspores (arrows). X 155.

30. Microspores. Note trilete suture. X 900.

31. Fluke-tipped glochidia from the massula in Fig. 28. X 2300.

32. TEM cross-section through a microspore embedded in a massula. Note unlayered microspore wall (arrows), pseudocellular texture of massula, and bases of projecting glochidia (G). X 3600.

33. TEM cross-section of a megaspore (M) with attached massula (m). Microspores (small arrows) are embedded within massula. X 280.



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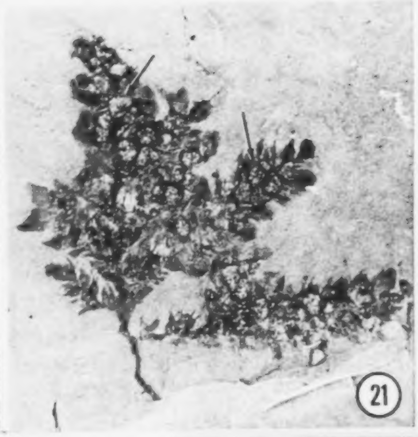

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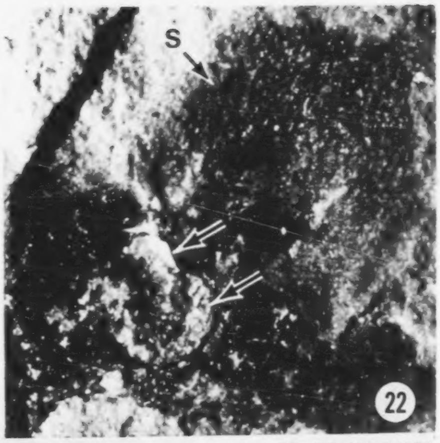

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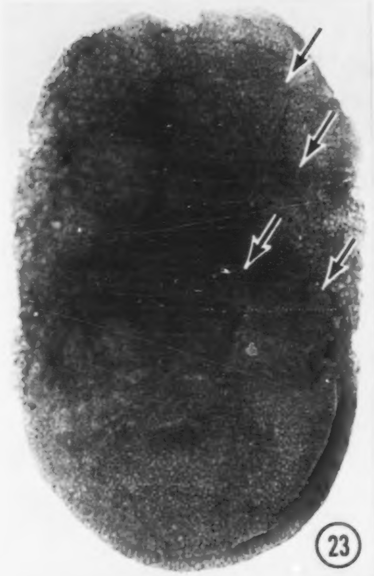

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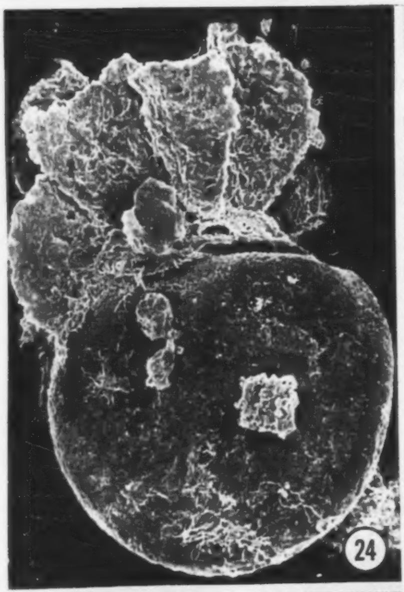

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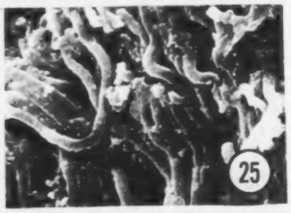

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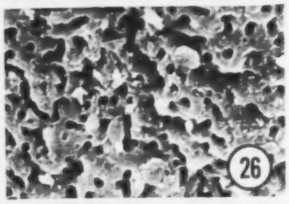

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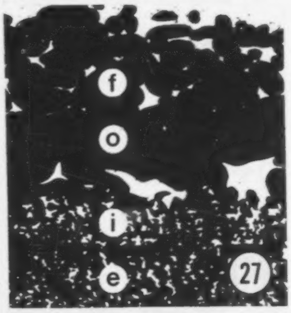

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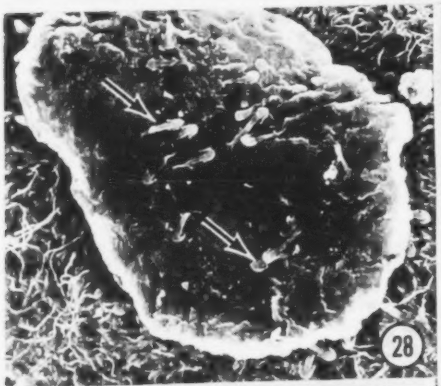

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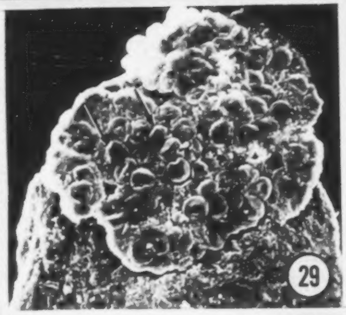

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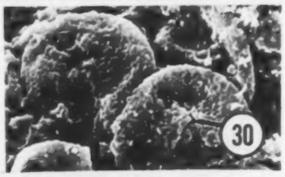

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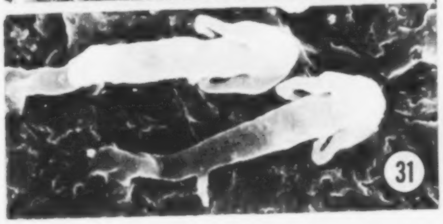

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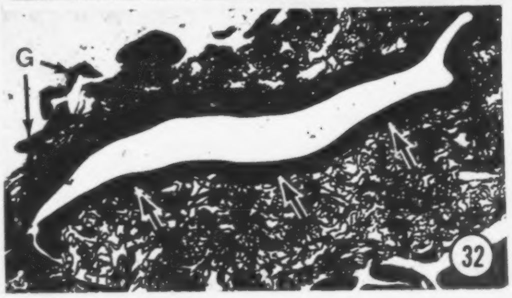

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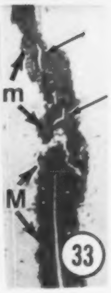


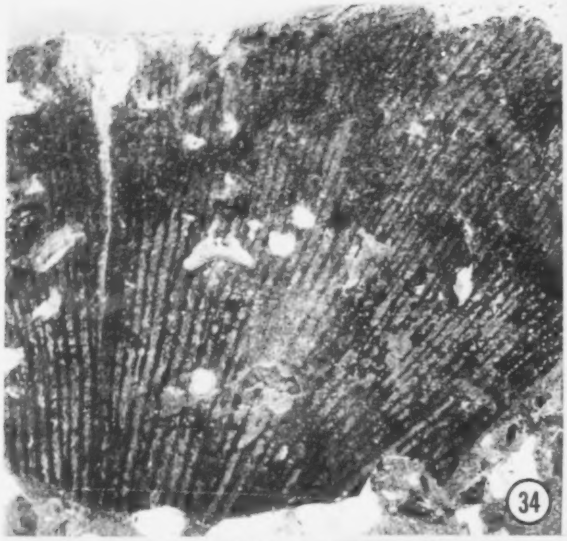
33

PLATE 5

Figure 34. Ginkgo L. sp. leaf fragment. S13,073. X 3.1.

Figures 35-41. Glyptostrobus europaeus (Brongniart) Heer

35. Branch with foliage and seed cone. (unnumbered) X 1.4.
36. Branches with foliage. S38,505A. X 0.6.
37. Branch with seed cones. S15,667. X 1.1.
38. Branch with pollen cones. S37,101. X 2.6.
39. Ovuliferous scale from a seed cone. S24,558. X 4.6.
40. Ovuliferous scale (OS) and bract (B). S36,989. X 9.0.
41. Winged seed. S36,941. X 6.0.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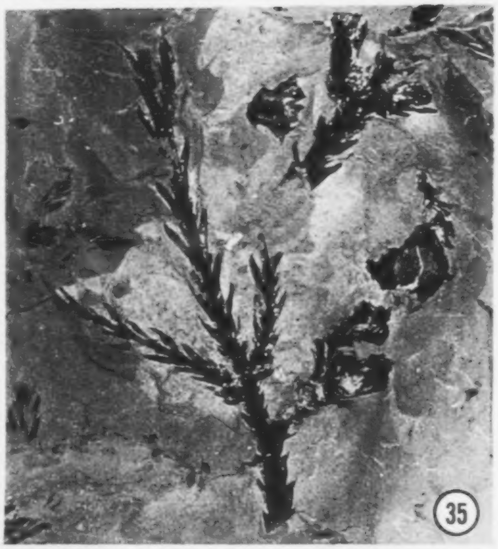
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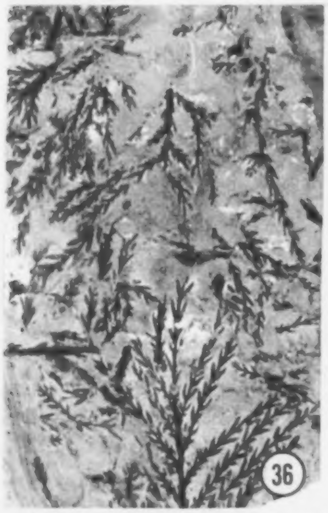
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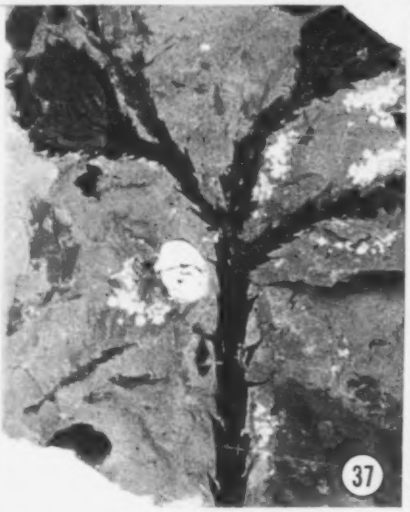
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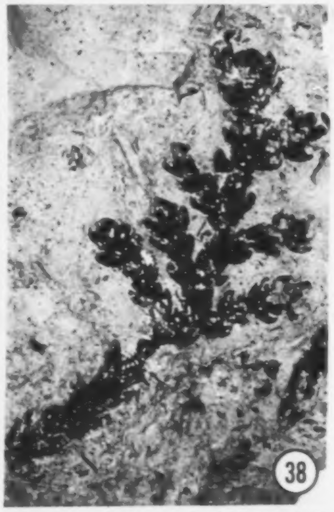
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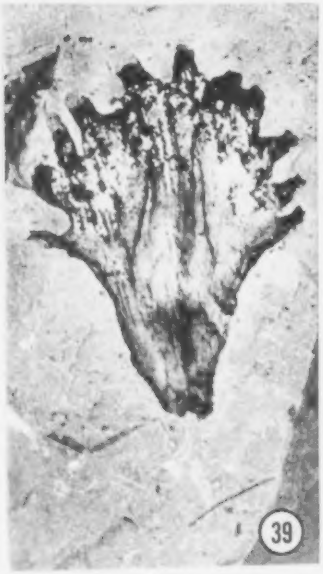
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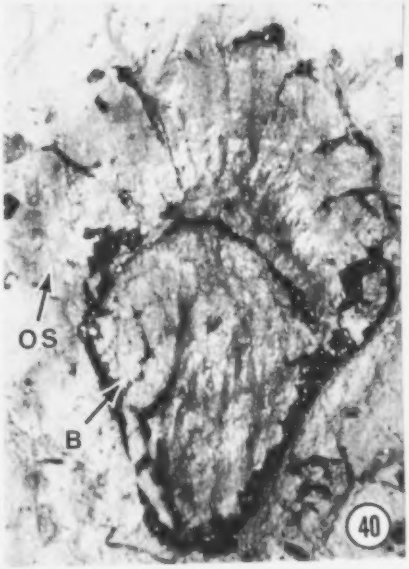

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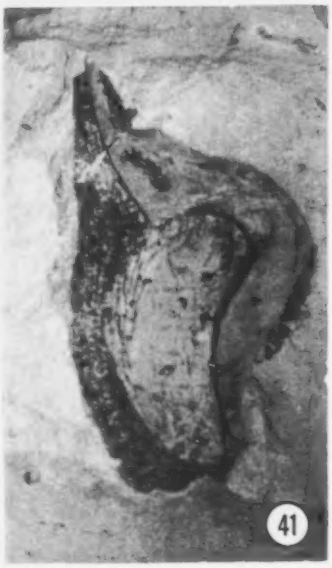
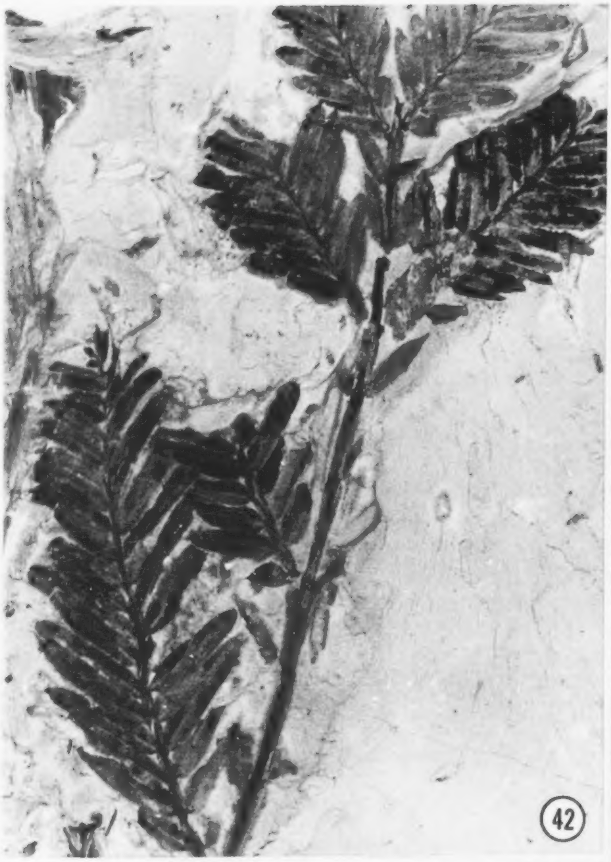

41

PLATE 6

Figures 42-47. Metasequoia occidentalis (Newberry) Chaney.

42. Branch with foliage. S11,217. X 2.4.
43. Seed cone. S24,520. X 2.4.
44. Pollen cones. S17,077. X 4.5.
45. Pollen cones with exserted sporophylls. S13,348A. X 1.4.
46. Seed cone. S13,151. X 2.4.
47. Winged seed. S24,534. X 6.0.



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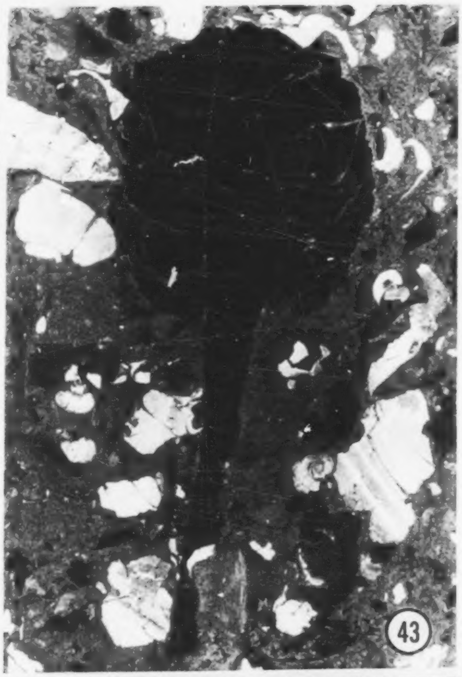

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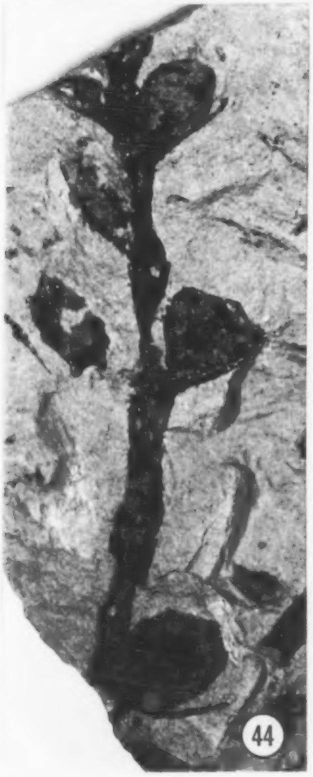

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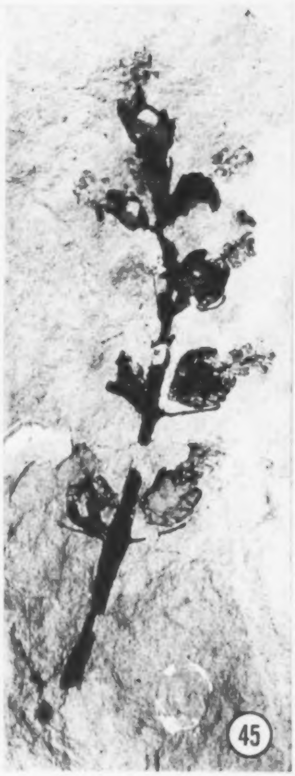

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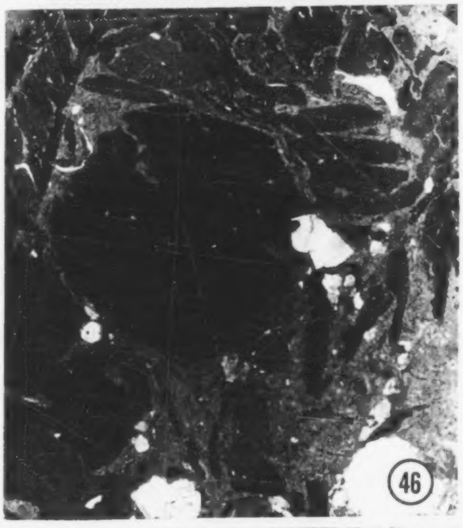

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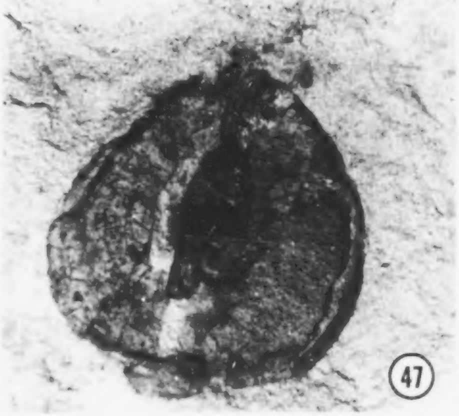

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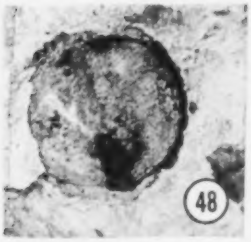
PLATE 7

Figures 48, 49. cf. Meliosma rostellata (Lesquereux) Crane et al.

48. Endocarp, showing keel. S9,909. X 5.2.
49. Endocarp, showing pore. S9,412. X 5.2.

Figures 50-59. Joffrea speirsii Crane & Stockey.

50. Leaf, showing shape and venation. S12,173. X 1.2.
51. Leaf margin. S40,177. X 2.1.
52. Pistillate inflorescences. S12,386. X 1.2.
53. Pistillate inflorescence, with carpels (C). Note abaxially coiled styles (S). S40,075. X 2.1.
54. Associated staminate inflorescence, composed of helically arranged, triangular bracts. S13,419. X 1.6.
55. Infructescence with mature follicles. S38,212. X 1.5.
56. Germinating seeds. Note seed body (s) and wing (w). S11,626. X 3.8.
57. Seedling with two cotyledons (note venation) and the beginnings of the first pair of leaves. S13,306a. X 4.0.
58. Seedling with cotyledons and first leaves. S13,306b. X 4.0.
59. Seedling showing one cotyledon and the first pair of leaves. Note venation and crenate margin. 17,093. X 2.2.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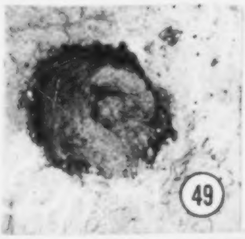
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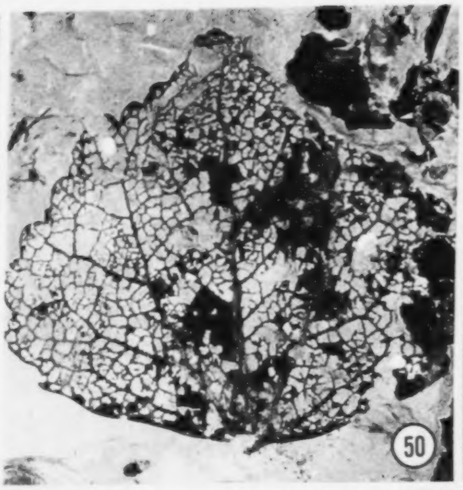
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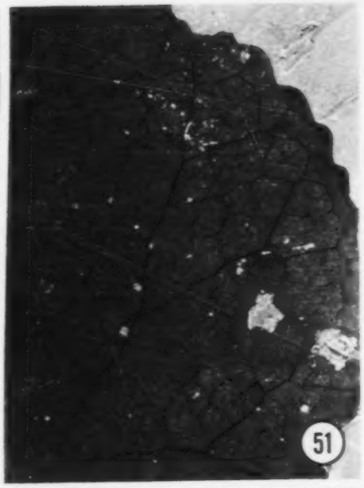
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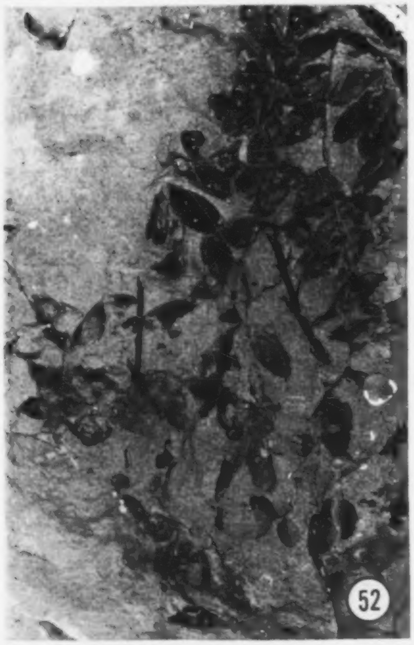
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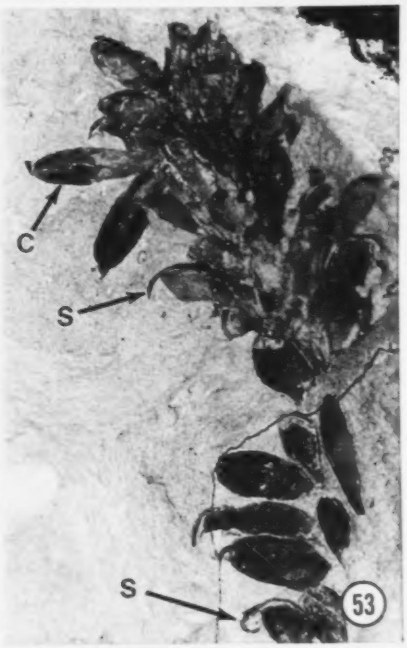

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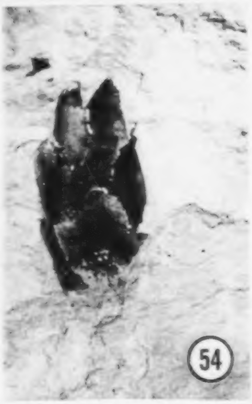
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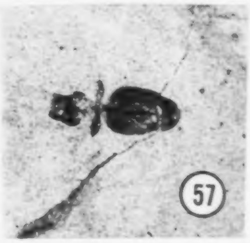
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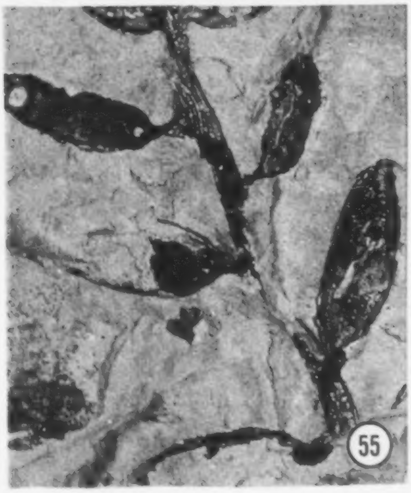
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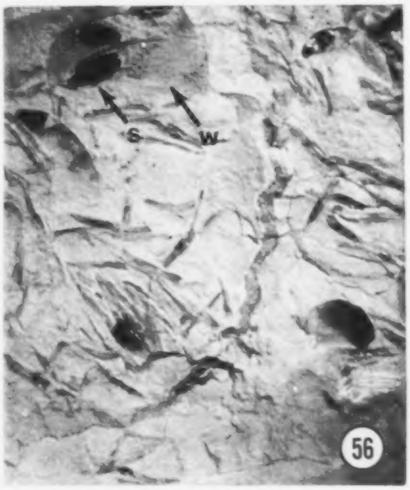

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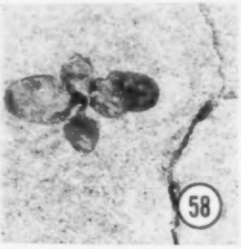
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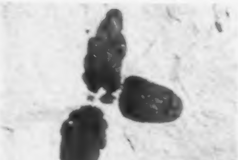
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PLATE 8

Figures 60-66. The Joffre Plane Tree.

Figures 60, 61. Platanus nobilis Newberry.

60. Leaf. S15,735A. X 0.7.
61. Leaf margin, showing venation and teeth. S15,765. X 1.3.

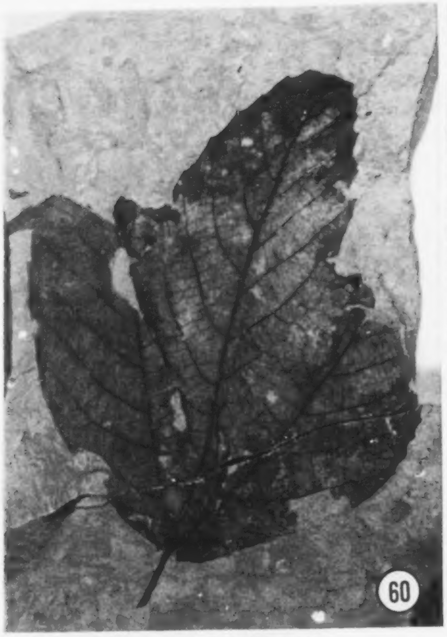
Figures 62, 63. Macginicarpa manchesteri Pigg & Stockey.

62. Infructescences showing attachment. S37,943. X 1.4.
63. Infructescence. Note achenes with curved styles (arrow). S37,948B. X 4.0.

Figure 64. Platanaceous seedling. S12,105. X 6.0.

Figure 65. Platananthus speirsae Pigg & Stockey, staminate inflorescence. S24,832. X 4.0.

Figure 66. Isolated group of platanaceous stamens. Note filaments (f), and cap formed by apical extension of the connective (c). S16,723. X 6.5.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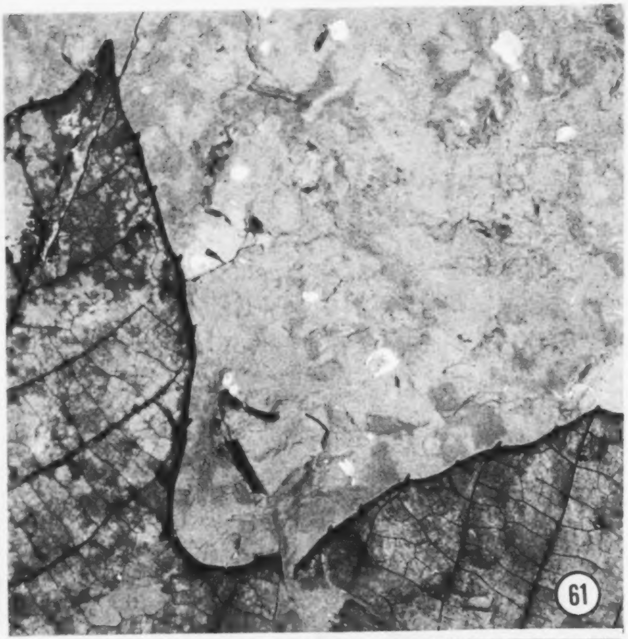
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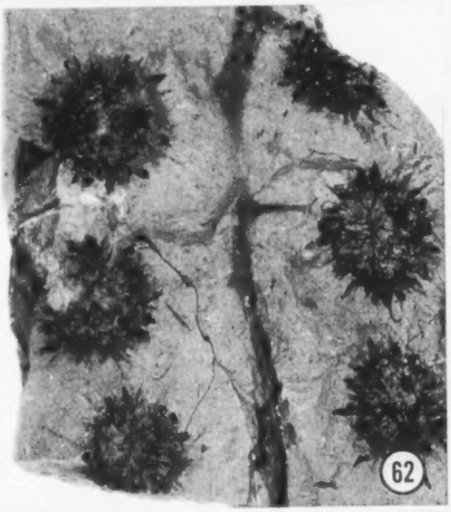
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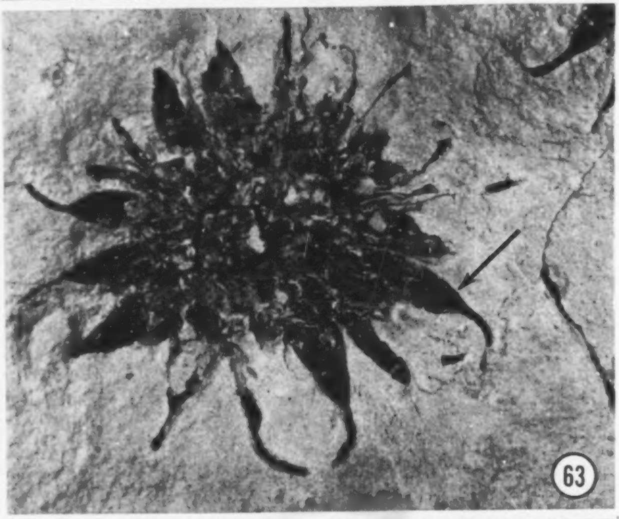
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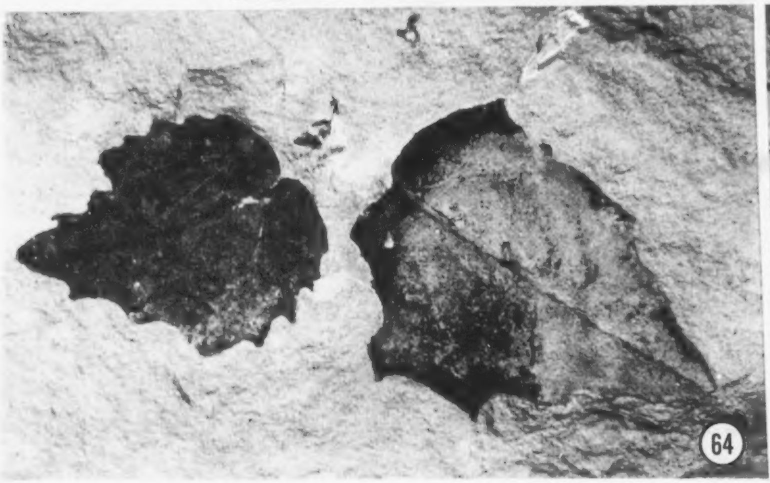
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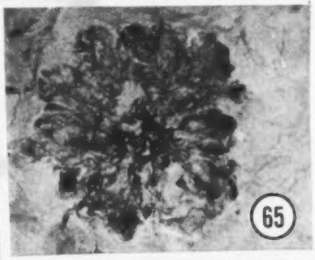
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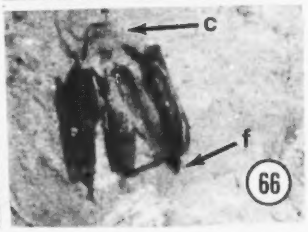
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PLATE 9

Figures 67-69. Chaetoptelea microphylla (Newberry) Hickey.

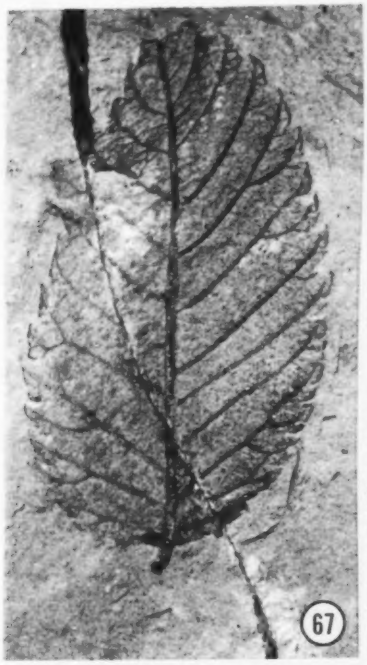
67. Leaf. S10,587. X 3.0.
68. Leaf. Note venation, and secondary teeth (arrows). S10,588. X 4.5.
69. Leaf. S10,971. X 3.0.

Figures 70, 73. "Acer" arcticum Heer.

70. Leaf margin. S12,060. X 2.0.
73. Leaf base. S12,029. X 1.4.

Figures 71, 72, 74. Deviacer Manchester sp.

71. Samara. Note attachment scar (arrow). S16,623. X 3.6.
72. Samara. S16,626. X 3.6.
74. Exposed nutlet. S16,633. X 5.0.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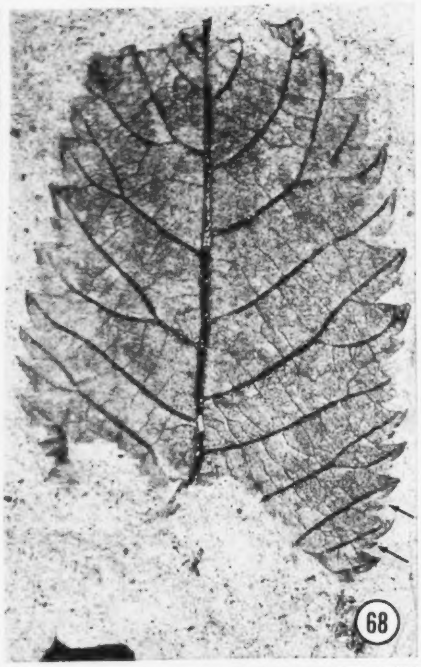
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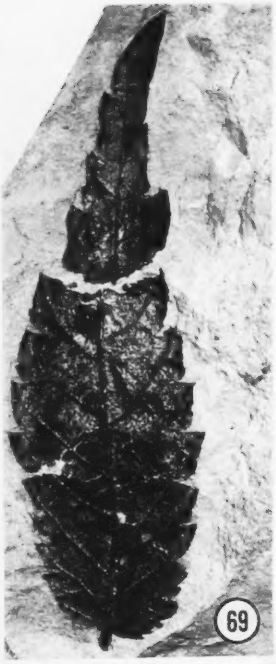
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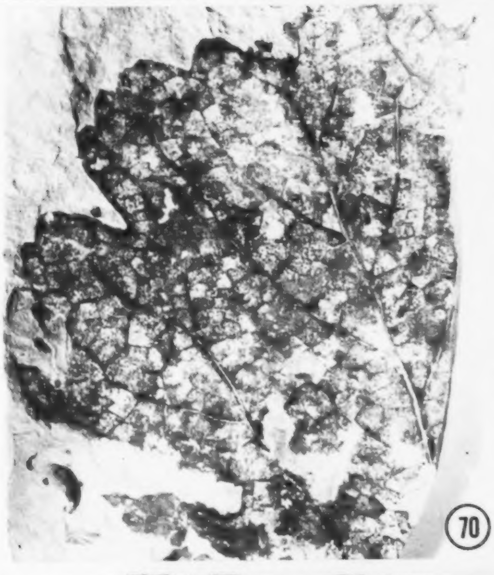
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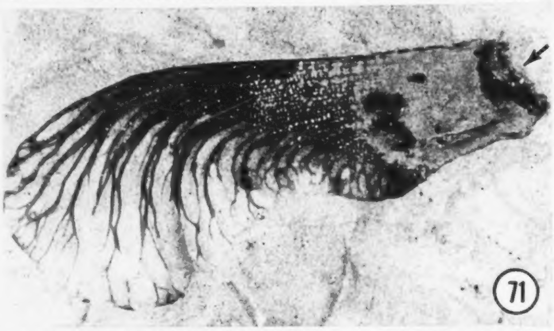
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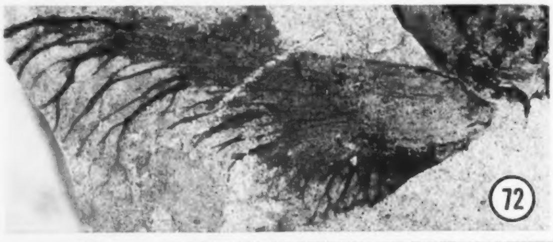
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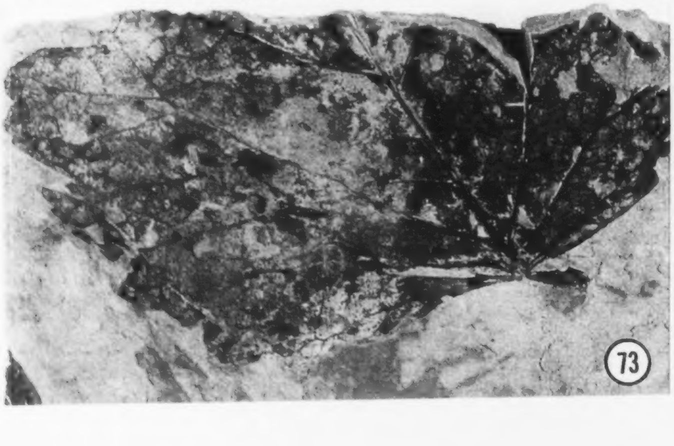
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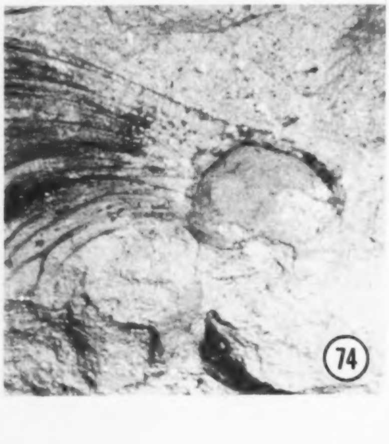
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PLATE 10

Figures 75, 76. "Viburnum" cupanioides (Newberry) Brown.

75. Leaves on slab. S8,043. X 0.9.
76. Three leaves. Note margin and venation. S8,043. X 0.7.

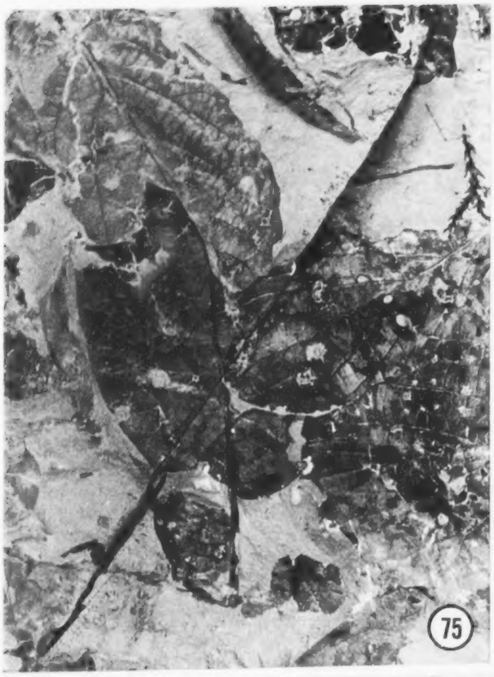
Figures 77, 78. Averrhoites affinis (Newberry) Hickey.

77. Leaf. S15,553. X 2.0.
78. Venation and margin. S37,291. X 2.5.

Figure 79. Unidentified leaf 1. S12,132. X 4.0.

Figures 80, 81. Unidentified leaf 2.

80. Venation and margin. Note small tooth (arrow). S16,943. X 5.2
81. Leaf base. S16,943. X 3.0.



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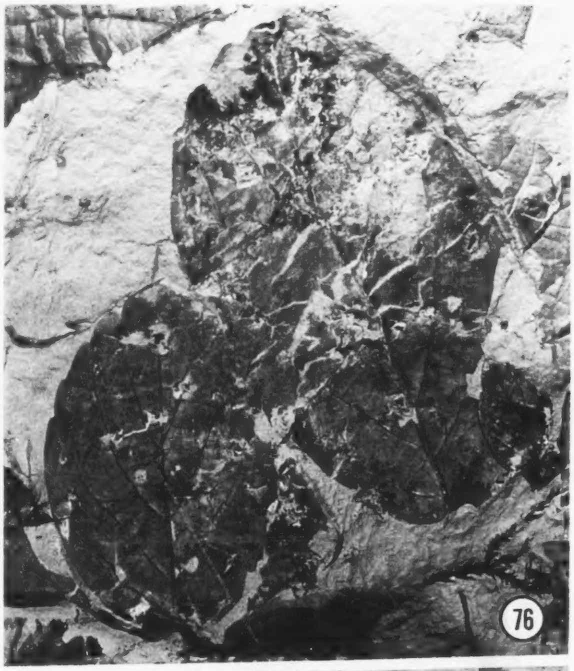

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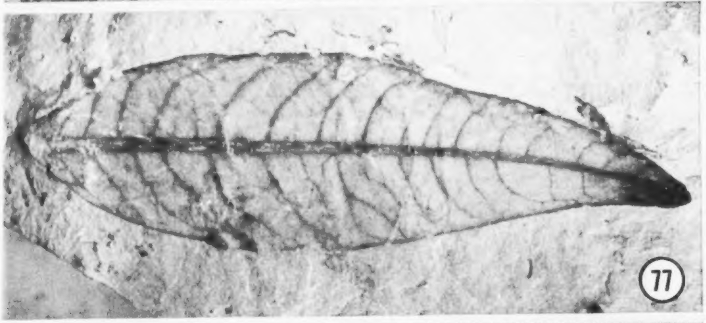

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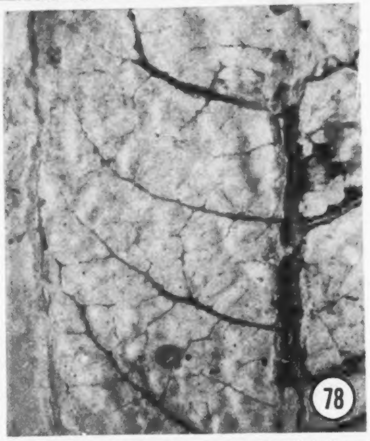

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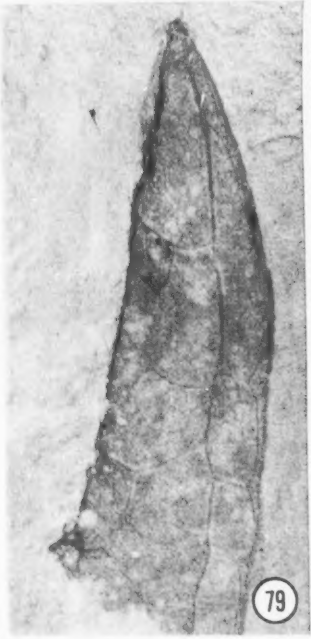

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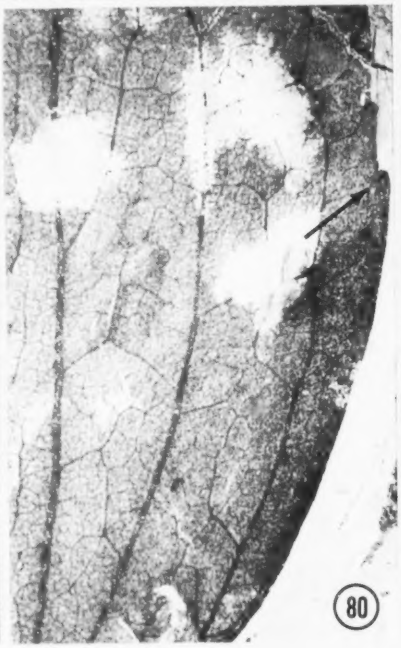

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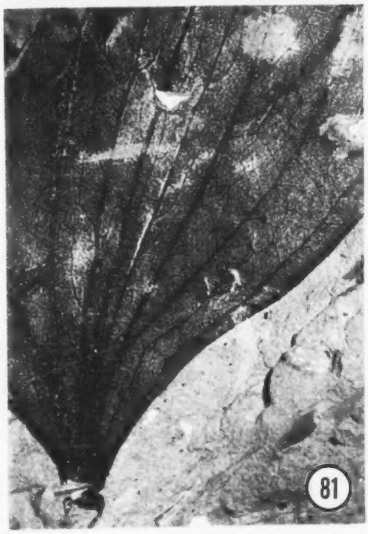


81

PLATE 11

Figures 82, 83. Wardiaphyllum daturaefolium (Ward) Hickey.

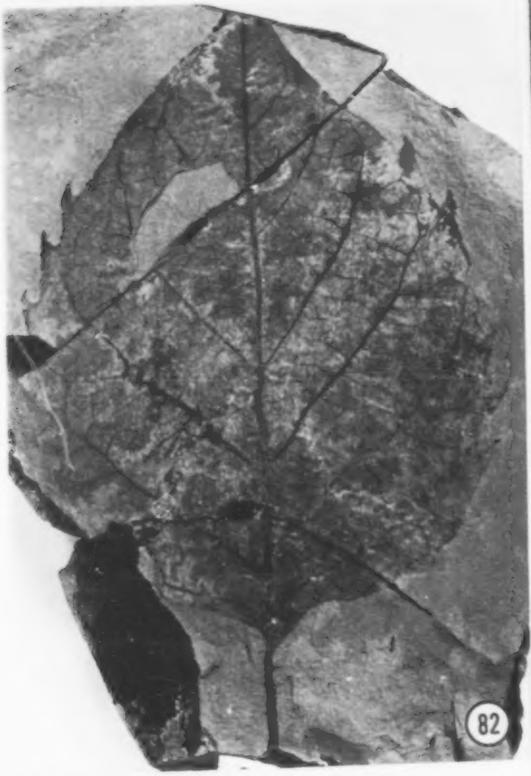
82. Leaf. S15,964B. X 0.9.
83. Venation and margin. S12,089. X 3.0.

Figures 84. Populus penhallowi Bell.

84. Leaf. S40,478. X 1.4.

Figures 85, 86. Fortuna marsilioides (Bell) McIver & Basinger.

85. Leaf with serrate margin. S16,661. X 3.0.
86. Two leaves on slab. S16,660. X 1.4.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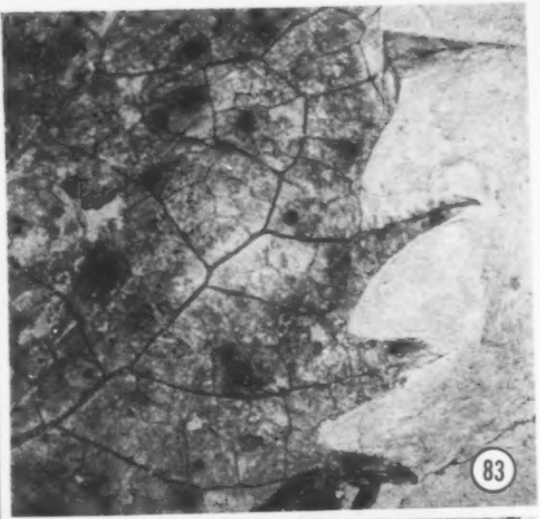
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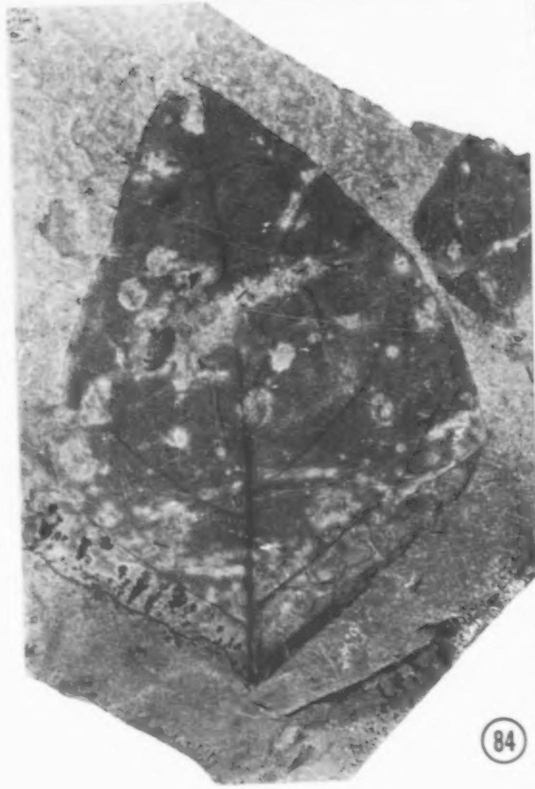
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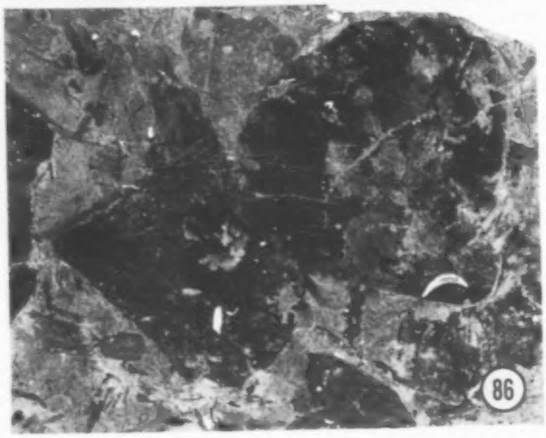
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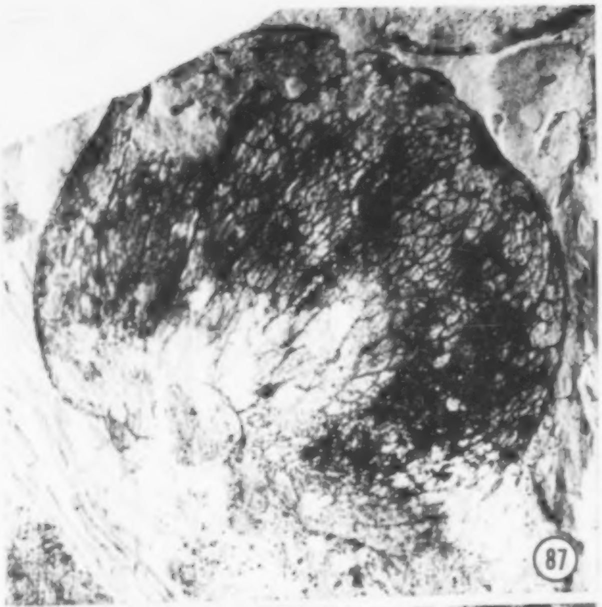
PLATE 12

Figures 87-92. Spirodela-like monocot.

87. Venation and margin. S37,122A. X 4.1.
88. Thallus showing pubescent surface, centrum (C), primary root (R) and filiform rootlets (r). S12,335B. X 4.0.
89. Thallus with centrum, primary root, and filiform rootlets. Lateral rootlets (arrows) branch from the primary root. S12,335B. X 2.6.
90. Pollen grain. Note single pore and echinae. X 3,500.
91. Thallus with attached daughter plant (arrow). S37,123. X 4.4.
92. TEM cross-section of pollen wall showing foot layer (f) and tectum (t), separated by a very thin laryer of granular/columellar material (arrow). Note echina (e) with slightly constricted base. X 5,700.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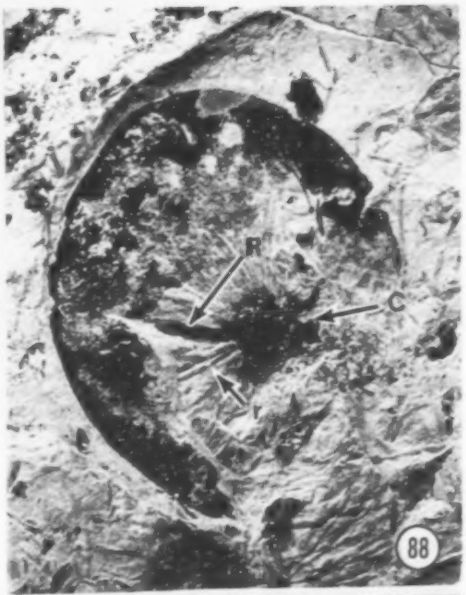

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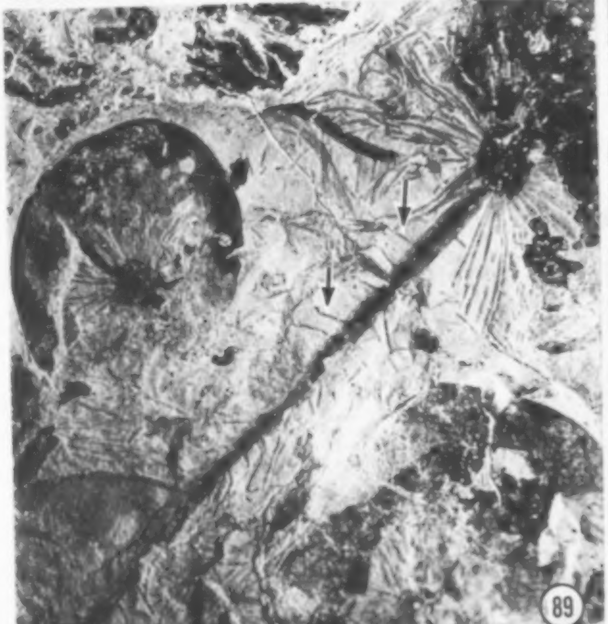
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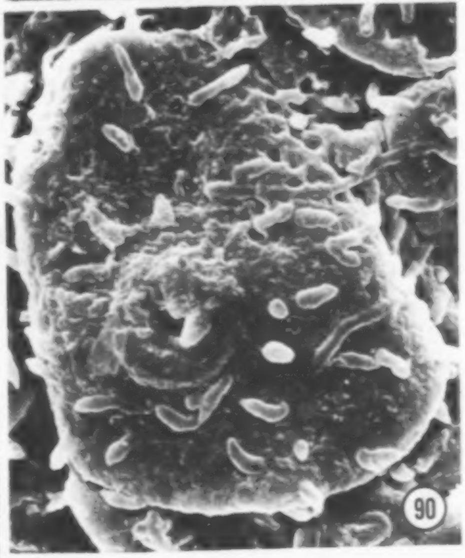
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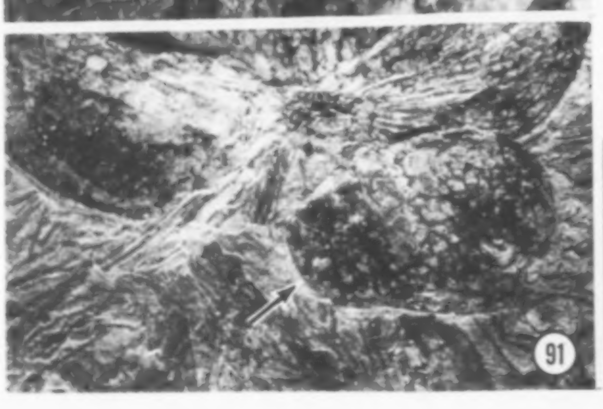
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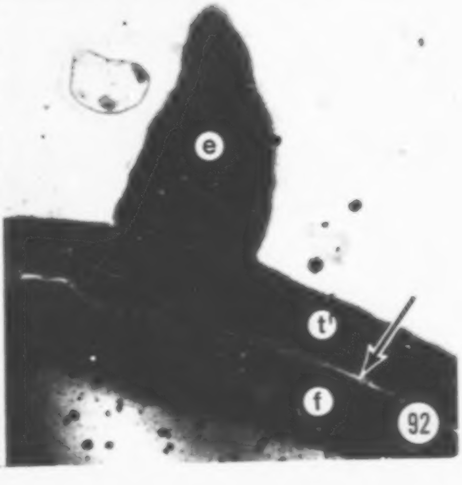

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PLATE 13

Figures 93, 94. Unidentified aquatic leaf.

93. Leaf, showing margin and venation. S11,301. X 4.4.
94. Leaf, showing base. S11,299. X 2.6.

Figures 95, 96. Cone-like infructescence.

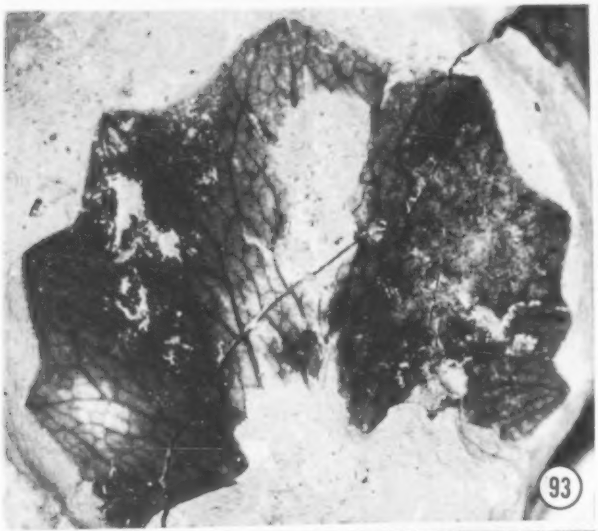
95. Broken infructescence. S8,093A. X 2.7.
96. Intact infructescence. Note globose shape. S8,057B. X 2.8.

Figures 97, 98. Unidentified seed or fruit.

97. Seed or fruit, showing notch and ornamentation. S13,346. X 4.2.
98. Seed or fruit, showing rim. S10,859. X 4.7.

Figures 99, 100. Unidentified branching aquatic plant.

99. Branching system, showing axis (arrow), and bud (small arrow). S24,564. X 1.4
100. Branching system. S11,312. X 1.4.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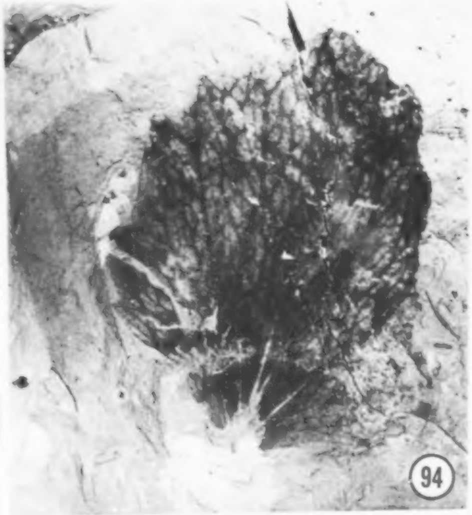
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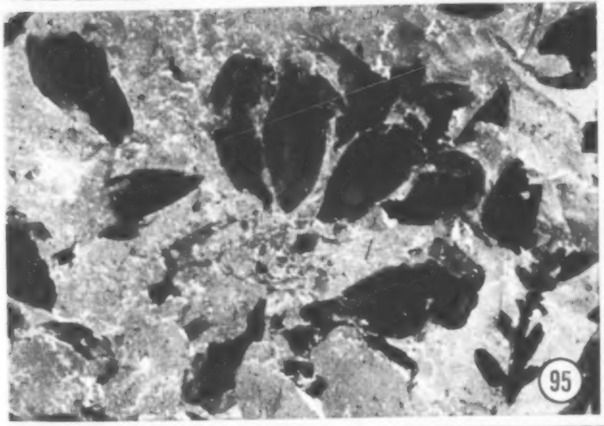
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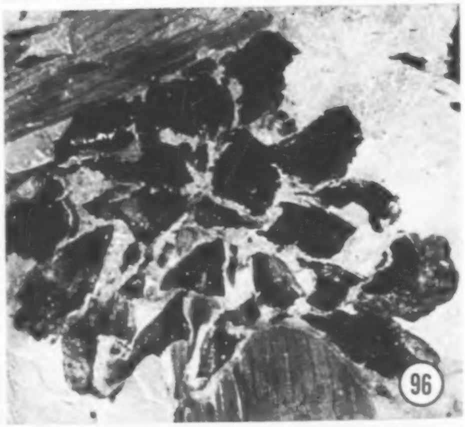
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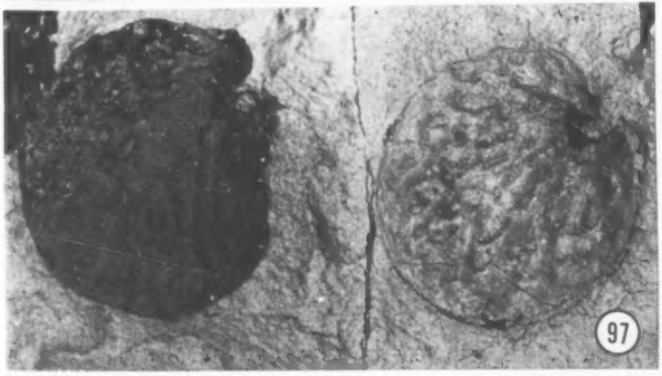
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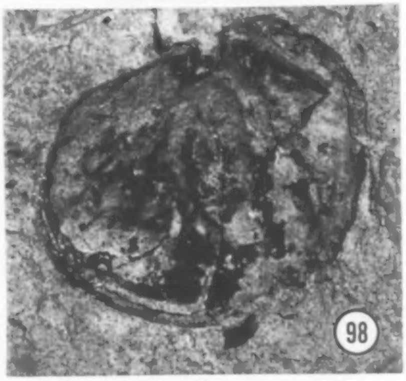
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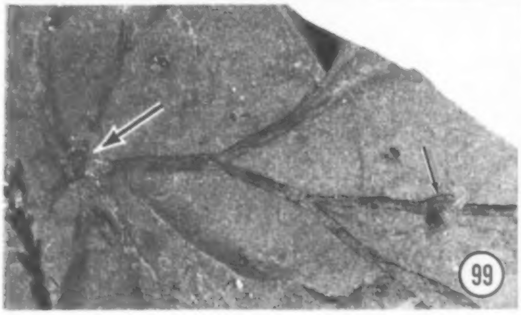
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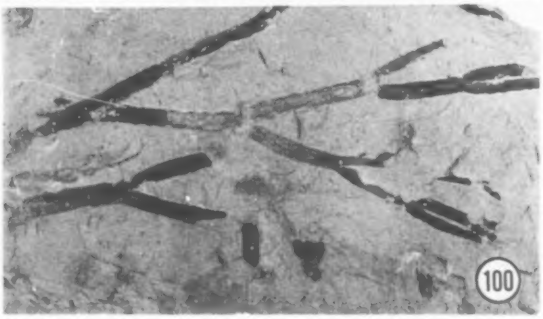
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PLATE 14

Figures 101-103. Lilialean monocot.

101. Specimen with leaves (L), rhizome (R), and roots (r). S39,421. x 0.8.

102. Closer view of rhizome, showing leaves (L), roots (r), and root scars (s). S39,421. X 3.1.

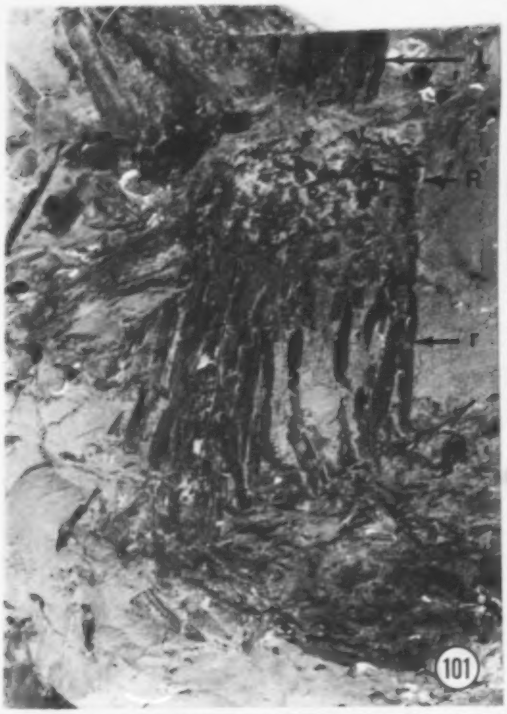
103. Leaf fragment showing venation. Note pattern produced by alternation of weaker and stronger veins S8,057B. X 4.4.

Figures 104-106. Unidentified sheathing structures.

104. Note scars (s), stem (S), and axillary bud (b). S17,179A. X 4.7.

105. Note scars (arrows). S16,682. X4.0.

106. Note segmented appearance produced by arrangement of scars. S40,964B. X 4.7.



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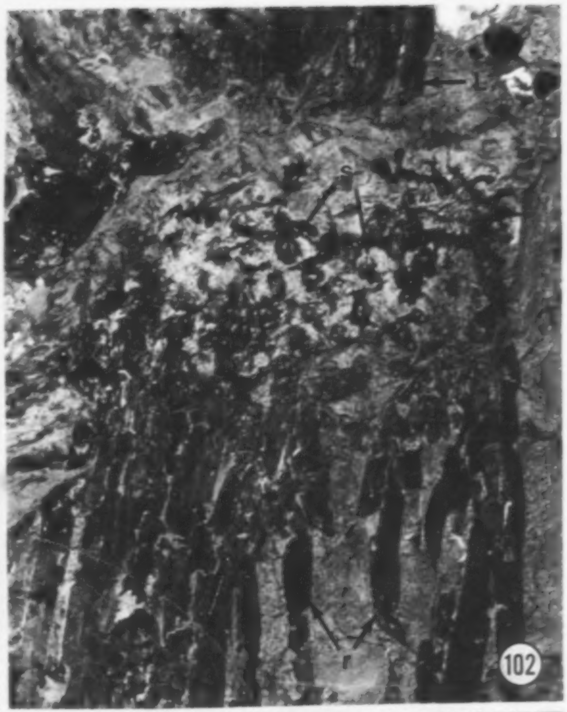

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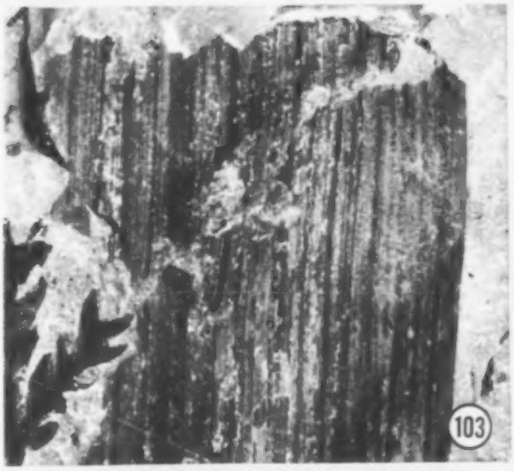

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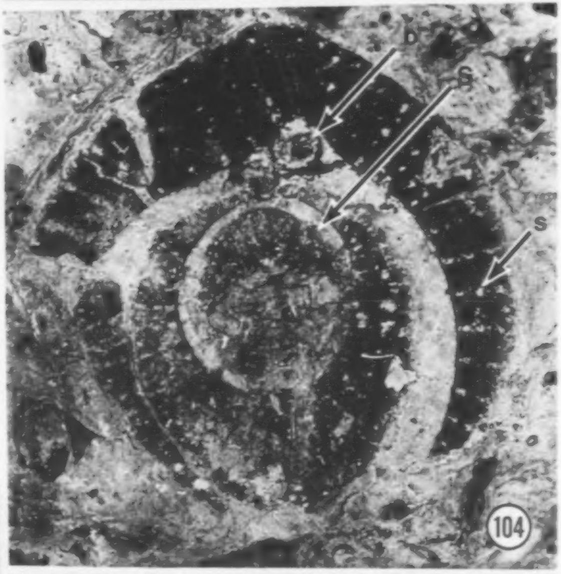

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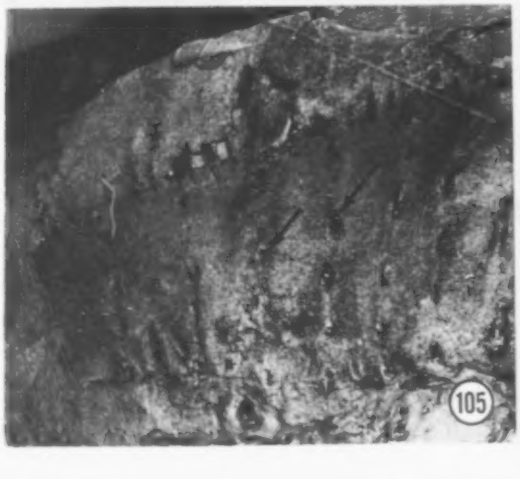

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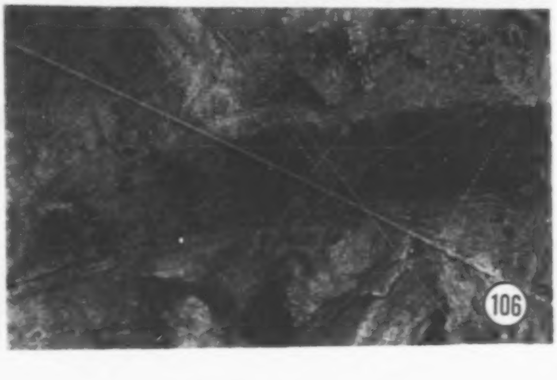


106

PLATE 15

Figures 107, 108. Alismaphyllites grandifolius (Penhallow) Brown.

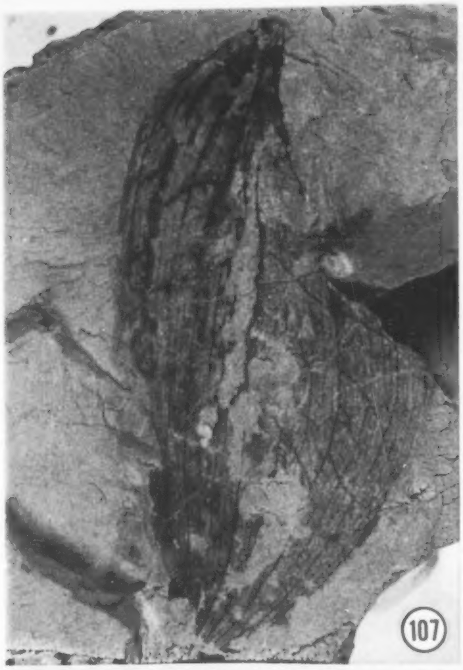
107. Leaf, showing shape and venation. S16,944. X 1.9.
108. Venation. S16,943B. X 4.7.

Figures 109, 110. Zingiberopsis attenuata Hickey.

109. Fragment of a large leaf. Note costa (arrow). S15,564. X 0.6.
110. Venation and margin. S16,973A. X 3.2.

Figure 111. Leaves of lilialean monocot and Glyptostrobus. S15,592A. X 0.6.

Figure 112. Striated seeds. S13,342. X 2.7.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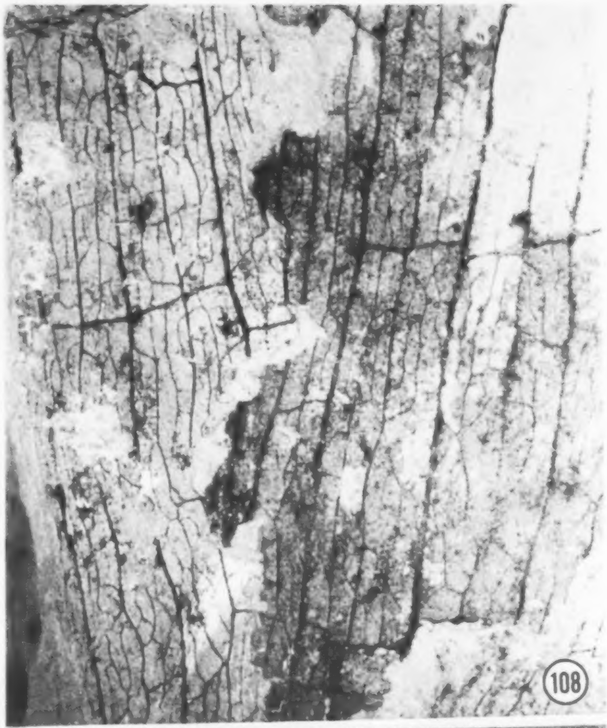
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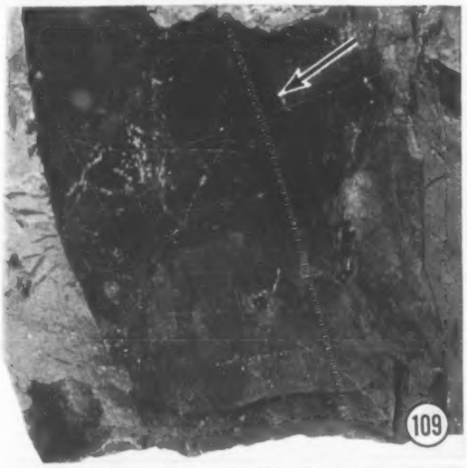
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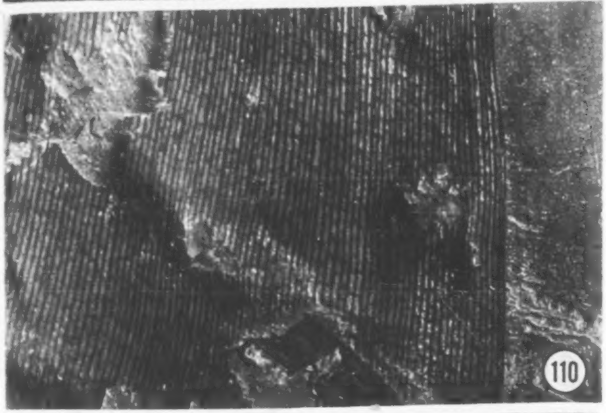
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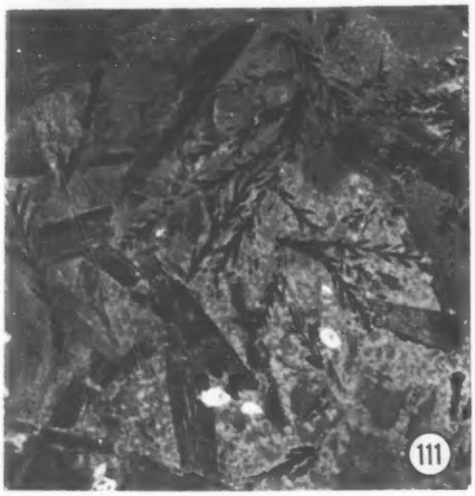
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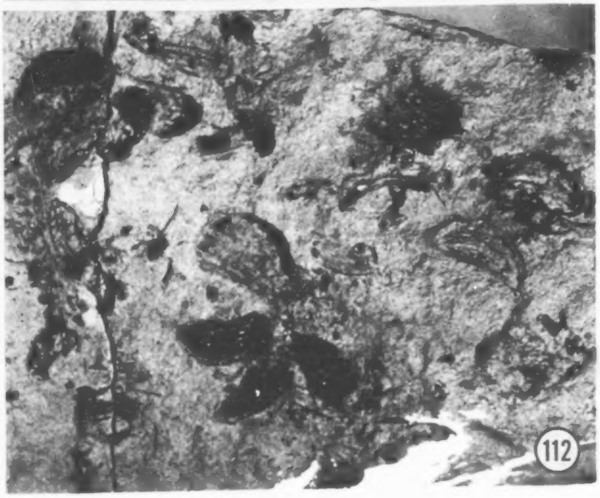

(112)

APPENDIX A

GEOLOGICAL DESCRIPTIONS

APPENDIX A

GEOLOGICAL DESCRIPTIONS

UNIT 1: LOWER LEVEL BED

Typical Thickness: 4-8 cm. Elevation: about 830 m.

Lithology: Claystone, medium to dark grey, soft, overlain by 1-2 cm of coal. This is the Lower Level bed described by Fox (1990). Some of the mammal jaws were found oriented more or less vertically in the clay (A. Lindoe, pers. comm.), suggesting that the bedding was disturbed by bioturbation, soil processes or rooting prior to the deposition of the coal. The bed is underlain by a thick, medium grey mudstone that contains small fragments of mollusc shells, fine plant detritus, and root traces.

Facies Relationships: This unit was quarried to the east of Trench 3. A very similar soft claystone that may be correlative with this bed can be seen at the base of the sandstone exposures along the north side of the river.

Flora: None.

Fauna: Mammals described by Fox (1990); crocodile, turtle, salamander and fish bones (Speirs, pers. comm.).

Environment of Deposition: Swamp (coal layer) underlain by clay.

UNIT 2: FLUVIAL CHANNEL SANDSTONE

Typical Thickness: 14 m.

Lithology: Sandstone, lithic (salt and pepper); medium-grained with occasional fine-grained zones; coarser grained at base with small (1-2 cm) mudstone clasts; light grey, weathering to greenish, yellowish, and rusty brown; scattered very large concretions.

Facies Relationships: The sandstone may be thinning toward the west (Trench 1). It is likely correlative with the sandstone exposed along the cliffs across the river from Joffre Bridge Roadcut. That sandstone is more than 10 m thick, medium grained, with epsilon crossbedding, becoming finer grained with planar bedding near the top of the cliffs.

Flora: Poorly preserved, fragmentary Metasequoia, Ginkgo, Joffrea and Platanus leaves; Joffrea follicles; Equisetum rhizomes; fragments of coalified wood; and root traces.

Fauna: Rare molluscs and small fragments of bone.

Environment of Deposition: Fluvial channel; bed-load deposits. Only robust material was preserved.

UNIT 3: CHANNEL-FILL SILTSTONE SEQUENCE

Typical Thickness: 35 cm.

Lithology: Siltstone, tan to light green, thin bedded, with frequent thin interbeds of fine-grained sandstone.

Facies Relationships: Present in the western part of the site.

Flora: Joffrea and Platanus leaves, inflorescences, fruits, seeds and seedlings, Deviacer samaras, Chaetoptelea leaves.

Fauna: Fish scales.

Environment of Deposition: As the active river channel (Unit 2) shifted eastward, the abandoned channel gradually became less active but still received some silt- and sand-laden water. Organs of riparian taxa were washed into this quieter environment and preserved in the silt and mud. Lenses of seedlings indicate that portions of these sediments were at times emergent and then subsequently inundated, burying the seedlings in place.

UNIT 4: LOWER LACUSTRINE SEQUENCE

Typical Thickness: 30 cm.

Lithology: Mudstone, tan to light green, thin bedded, with scattered small mollusc shells, becoming silty toward base.

Facies Relationships: Present throughout western part of site.

Flora: Joffrea and Platanus leaves, inflorescences, fruits, seeds; Deviacer samaras; Chaetoptelea leaves; and various seeds.

Fauna: Insects (dragonfly and beetle wings; larvae; Appendix B).

Environment of Deposition: Lacustrine, an oxbow lake (Lake Speirs) that formed after the abandonment of the fluvial channel (Unit 2).

UNIT 5: MOLLUSC LAYER

Typical Thickness: 6-12 cm (including coal).

Elevation: about 845 m

Lithology: Dark grey to black, coaly, calcareous mudstone, well indurated with calcite cement, hard. Usually overlain and underlain by 0.5-2.0 cm coal. Includes abundant small freshwater bivalve and gastropod shells, as well as plant, insect and vertebrate remains.

Facies Relationships: Present throughout the western part of the site but absent in the east (Trench 3).

Flora: Metasequoia foliage and cones (abundant); Glyptostrobus foliage; Platanus leaves and fruits; fragments of Ginkgo leaves (rare); miscellaneous seeds.

Fauna: Scattered fish scales and bones. Isolated mammal jaws (Fox, 1991). Larvae of Tipulidae (craneflies) (Appendix B).

Environment of Deposition: A marsh, formed during a period of low water level in the oxbow lake (Unit 4), with little flooding or clastic sedimention from the fluvial channel (Unit 2). Small maounts of peat (coal) were deposited. The environment was favorable for molluscs. Cementation by calcite occurred after most of the plant material had become crushed and flattened or coalified.

UNIT 6: UPPER LACUSTRINE SEQUENCE

Typical Thickness: 85 cm.

Lithology: Mudstone, light grey to light green and tan, thin bedded, with traces of bioturbation; grading to siltstone in the upper part with increasing frequency of thin interbeds of silt and fine sand. This sequence includes several important fossiliferous horizons and is subdivided into Units 6a-6d described below.

Facies Relationships: The upper part coarsens gradually upward, developing frequent thin interbeds of silt and fine sand toward the top. This unit is present throughout the western part of the site (Trenches 1 and 2). It is absent at Trench 3, where the equivalent interval is occupied by a greenish-brown siltstone that may be a levee deposit.

Flora: See units below.

Fauna: Mass-death layer of fish remains at top (Unit 6d). Scattered fish scales and shells of small freshwater bivalves and gastropods throughout. Insect remains near base (Units 6a & 6b).

Environment of Deposition: Lacustrine; initially shallow during Units 6a, 6b, becoming deeper and eventually connected to the active channel through a breached levee during Units 6c, 6d.

Unit 6a: Concretion Zone

Typical Thickness: 10-15 cm.

Lithology: Mudstone and claystone, light to medium grey, with plant remains. Includes calcite-cemented mudstone concretions in west (Trench 1); uncemented in east (Trench 2).

Facies Relationships: Present in the western part of the site (Trenches 1 & 2). The concretions lie directly on top of the Mollusc Layer and appear to be present only at the westernmost edge of the site (Trench 1).

Flora: Glyptostrobus branches and cones, Metasequoia foliage, lilialean leaves (abundant); Osmunda pinnules, Joffrea leaves, "Viburnum" leaves (fairly common); fragments of Zingiberopsis leaves, and the cone-like infructescence (uncommon).

Fauna: Insect wings (Appendix B). Scattered fish scales.

Environment of Deposition: Lacustrine; water levels rose, gradually drowning the swamp (Unit 5). Most of the plant material had become crushed and flattened prior to mineralization by calcite.

Unit 6b: Aquatic Plant Zone

Typical Thickness: 10 cm.

Lithology: Mudstone and claystone, light grey at base to light green at top, occasionally silty, with plant and insect fossils.

Facies Relationships: Present throughout the western part of the site.

Flora: Scattered *Azolla* sporophytes near top. Whole *Spirodela* and *Ricciopsis*, rare isolated *Fortuna* leaves, and fragments of lilialean leaves at base.

Fauna: Insect wings and larvae (Appendix B).

Environment of Deposition: Lacustrine; shallow water, near shore. *Azolla* and *Spirodela* are free-floating aquatic genera; ricciaceous liverworts grow in or near shallow water, and some species have a free-floating form; the lilialean monocot and *Fortuna* grew rooted in shallow water.

Unit 6c: Barren Zone

Typical Thickness: 60 cm.

Lithology: Mudstone, light green and tan, thin bedded, with scattered small mollusc shells, and traces of bioturbation. Thin interbeds of silt and fine sand become common toward top, where siltstone becomes the dominant lithology.

Facies Relationships: Coarsens toward top, with frequent thin interbeds of silt and fine sand. Present throughout the western part of the site.

Flora: Scattered scraps of plant material.

Fauna: Scattered small molluscs and fish scales.

Environment of Deposition: Lacustrine. Coarsening at top reflects influence of prograding crevasse splay (Unit 7) and reconnection with an active fluvial channel.

Unit 6d: Fish Layer

Typical Thickness: 1 cm. Elevation: about 846 m

Lithology: Mudstone, medium grey, silty, thin bedded, rust stained, with abundant remains of freshwater fishes (Appendix B).

Facies Relationships: Present in the western part of the site, where it has been excavated over an area of about 200 square metres to date.

Flora: None.

Fauna: Freshwater fish remains described by Williams and Wilson (1988), Wilson and Williams (1991), Murray (in prep.). As of 1991, 45 specimens of an osmerid (smelt), 1,795 specimens of a paracanthopterygian, two articulated specimens of an osteoglossomorph, a few disarticulated bones of an amiid, and one articulated crustacean had been quarried from the Fish Layer by UALVP.

Environment of Deposition: Lacustrine; likely connected to an active fluvial channel through a breached levee.

UNIT 7: CROSSBEDDED SANDSTONE

Typical Thickness: > 150 cm.

Lithology: In west (Trench 2) fine-grained, finely crossbedded sandstone with climbing ripples; scattered large molluscs; large concretions. In east (Trench 3), medium-grained sandstone with mudstone clasts and erosional basal contact.

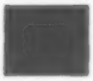
Facies Relationships: This unit becomes fine-grained and strongly crossbedded westward from Trench 3. The basal contact is erosional at Trench 3, but interfingers with mudstones at Trench 2. Unconformably overlain by glacial till.

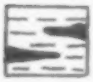
Flora: Scattered scraps of leaves and twigs.

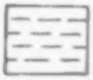
Fauna: Scattered large bivalves.

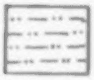
Environment of Deposition: Crevasse splay, prograding westward from breached levee of active fluvial channel in east (Unit 2), into lake in west (Unit 6). Coarser grained facies at Trench 3 may represent a distributary channel within the splay near the breached levee.

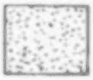
EXPLANATION OF SYMBOLS

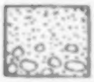

Coal

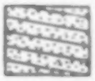

Coaly mudstone

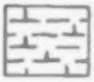

Mudstone

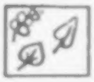

Siltstone

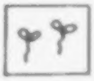

Sandstone

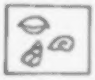

Sandstone, with clasts

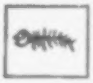

Sandstone, crossbedded


Mudstone, calcareous

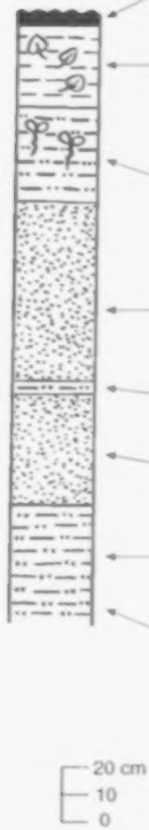

Fossils: plant material


Fossils: plant seedlings


Fossils: mollusc shells


Fossils: fish remains

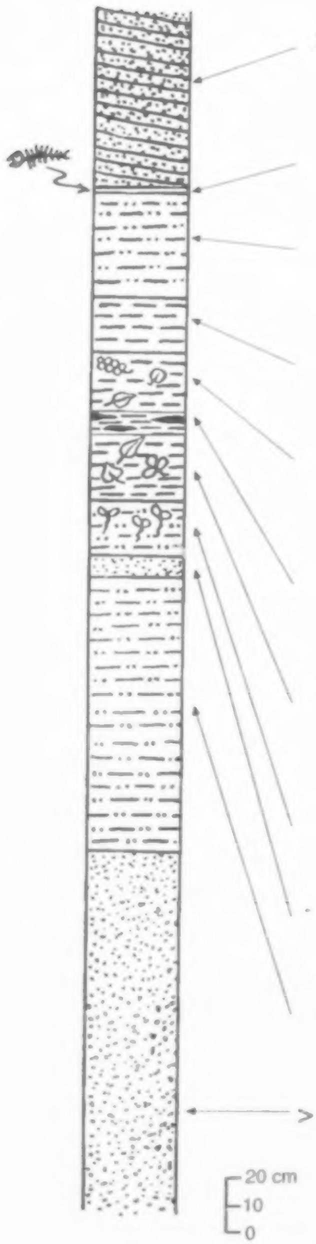
TRENCH 1



> 3 cm	Mollusc Layer, mudstone, dark grey, carbonaceous to coaly, abundant small bivialves & gastropods.
30	Mudstone, medium grey, beds ~ 2 cm thick, plant remains (Joffrea leaves, follicles), scattered small molluscs.
33	Siltstone, grey, with thin interbeds of sand; dicot seedlings.
65	Sandstone, fine-grained, tan to greenish weathering silty, micaceous, beds ~ 1-3 cm thick.
5	Siltstone, grey.
40	Sandstone, as above.
20	Siltstone, medium grey, beds ~ 1-3 cm thick, rare small fragments of plant debris.
> 35	Siltstone, greenish, rare small fragments of plant debris.

TRENCH 1: Near west end of site, 198 m west of Section boundary. Dug by track-mounted backhoe, August 1993. Uppermost beds were removed during previous fossil quarrying.

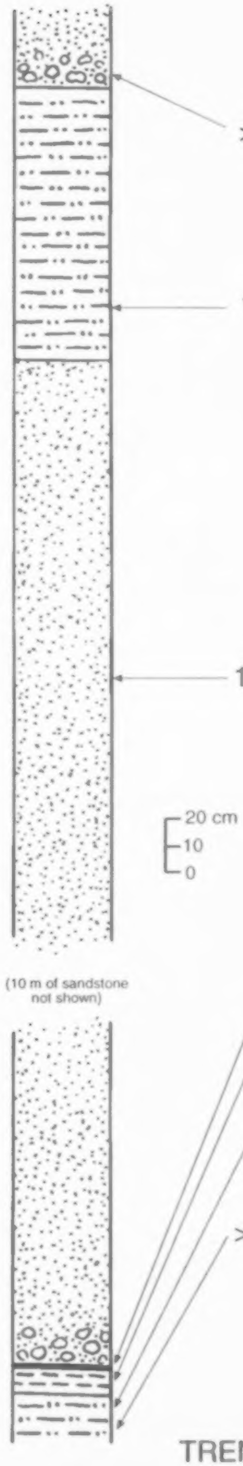
TRENCH 2



> 65 cm	Sandstone, fine-grained, tan, cross-bedded, beds ~2 cm thick, climbing ripples, large concretions; basal contact abrupt.
1	Mudstone, medium grey, silty, Fish Layer at base.
41	Siltstone, tan, frequent interbeds of grey mudstone; beds ~1 cm thick; mildly bioturbated; gradational to mudstone below.
21	Mudstone, medium grey, scattered thin interbeds of tan silt; gradational to unit below.
23	Mudstone & claystone, medium grey, rare silty interbeds; scattered bivalves, Glyptostrobus fragments near base; basal contact abrupt.
7	Mollusc Layer, claystone, dark grey, carbonaceous, 2 cm coal at top; abundant small bivalves & gastropods; basal contact abrupt.
25	Mudstone, medium grey, beds ~2-5 cm thick, scattered small bivalves; gradational into siltstone below.
20	Siltstone, medium grey, scattered thin interbeds of sand, no molluscs; dicot seedlings.
8	Sandstone, fine-grained, tan, micaceous; abrupt upper & lower contacts.
100	Siltstone, medium grey, scattered thin interbeds of tan sand; basal contact abrupt.
> 170	Sandstone, fine- to medium-grained, tan, micaceous, beds ~3-5 cm thick; large concretions; strongly weathered.

TRENCH 2: Near centre of site, 76 m west of Section boundary.
Dug by track-mounted backhoe, August 1993.

TRENCH 3



>30 cm Sandstone, medium-grained, salt & pepper, brown weathering, with clasts of greenish-grey mudstone, fragments of twigs; base abrupt, cuts into underlying siltstone.

100 cm Siltstone, greenish-brown; gradational contact with sandstone below.

13.5 m Sandstone, medium-grained, salt & pepper, light grey. Base coarse-grained, with scattered clasts of grey mudstone, Joffrea fruits, Equisetum rhizomes, fragments of dicot leaves and coalified wood.

1 cm Coal.

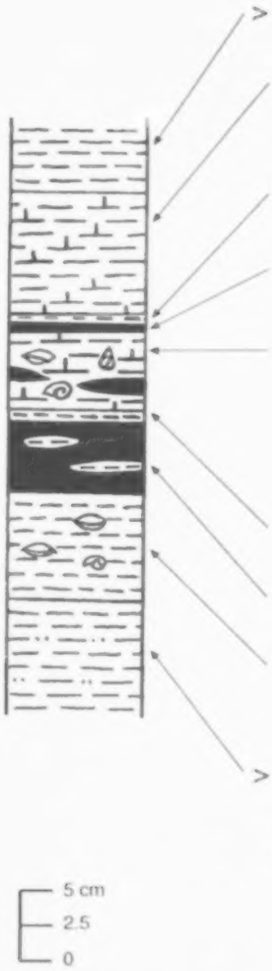
2 cm Claystone, dark grey, soft; Lower Level Vertebrate Bed of Fox (1990).

11 cm Mudstone, medium grey, hard, with small fragments of mollusc shells, coalified wood, Equisetum rhizomes, root traces.

>1.5 m Siltstone, medium grey, fissile, with fine fragments of plant debris & twigs, root traces.

TRENCH 3: About 10 m east of Section boundary at natural outcrop of uppermost sandstone. Dug by hand, July 1991.

MOLLUSC LAYER SECTION



> 5 cm	Claystone, light grey, scattered small molluscs.
9	Concretion Zone: claystone, medium-grey, containing individual broad, flat, calcite-cemented concretions.
0.5	Clay, soft, browm, weathered, with small molluscs.
1	Coal, weathered, shaley.
6	Mollusc Layer. Claystone, dark grey to black, carbonaceous to coaly, hard, calcite-cemented, with abundant small, white, crushed bivalve & gastropod shells.
1	Clay, soft, brown, weathered.
5	Coal, weathered, with lenses of brown clay.
8	Mudstone, tan, thin bedded, with scattered small molluscs.
> 50	Mudstone, tan, no molluscs.

MOLLUSC LAYER SECTION: About 15 m west of Trench 1; July 1991.

APPENDIX B

FAUNAL REMAINS

APPENDIX B

FAUNAL REMAINS

MAMMALS

JOFFRE BRIDGE ROADCUT, LOWER LEVEL (from Fox, 1991):

Multituberculata: *Ptilodus*, new species 1 of Krause (1982); *Prochetodon*, new species; *Mesodma pygmaea*; *Mimetodon silberlingi*; *Neoplagiaulax*, cf. *N*. *hazeni*; *Neoplagiaulax*, new species.

Marsupicarnivora: *Peradectes elegans*.

Lipotyphla: *Litocherus*, cf. *L*. *notissimus*; *Litocherus*, cf. *L*. *zygeus*; *Litolestes ignotus*; Erinaceidae, new genus and species. Lipotyphyla, unidentified genus and species.

Dermoptera: *Elpidophorus elegans*.

Primates: Microsyopidae, unidentified genus and species; *Ignacius frugivorus*; *Carpodaptes hazelae*.

Condylarthra: Arctocyonidae, unidentified genus and species; *Ectocion wyomingensis*.

Pantodonta: unidentified genus and species.

Eutheria, **order incertae sedis**, **Palaeoryctidae**: *Pararyctes patersoni*; cf. *Stilpnodon* sp.; **Palaeoryctidae**, unidentified genus and species. Pantolestidae: *Propalaeosinopa albertensis*; *Propalaeosinopa septenrionalis*.

JOFFRE BRIDGE ROADCUT, UPPER LEVEL (from Fox, 1991):

Lipotyphla: *Litocherus zygeus*.

Pantodonta: cf. *Titanoides*

FISH

Recent references concerning fish from Joffre Bridge Roadcut:

Li, G.-q. 1994. New osteoglossomorphs (Teleostei) from the Upper Cretaceous and Lower Tertiary of North America and their phylogenetic significance. Ph.D. thesis, University of Alberta, 200 p.

Li, G.-q. and Wilson, M.V.H. In press. The discovery of Heterotidinae (Teleostei: Osteoglossidae) from the Paleocene Paskapoo Formation of Alberta, Canada. Journal of Vertebrate Paleontology. (Name of species not yet published: *Joffrichtys* *symmetropterus*)

Li, G.-q. and Wilson, M.V.H. In press. Phylogeny of Osteoglossomorpha. *In*: Interrelationships of Fishes Revisited. *Edited* *by*: M.L.J. Stiassny, L. Parenti and G.D. Johnson. Acedemic Press, New York.

Murray, A.M. 1994. Description of two new species of basal paracanthopterygian fishes from the Paleocene of Alberta, and a phylogenetic analysis of the percopsiforms (Teleostei: Paracanthopterygii). M.Sc. thesis, University of Alberta, 175 p.

Murray, A.M. In press. A new Paleocene genus and species of percopsid, *Massamorichthys* *wilsoni* (Paracanthopterygii) from Joffre Bridge, Alberta, Canada. Journal of Vertebrate Paleontology. *Name not published yet.

Murray, A.M. and Wilson, M.V.H. Submitted. Phylogenetic relationships of the percopsiform fishes (Teleostei: Paracanthopterygii): order restored. Submitted to Copeia.

Williams, R.R.G. and Wilson, M.H.V. 1988. An osmerid fish from Paleocene freshwater sediments of Alberta. J. Vert. Paleont. **8** (Supp. to No. 3): 28A.

Wilson, M.H.V. 1980. Oldest known *Esox* (Pices: Esocidae), part of a new Paleocene teleost fauna from western Canada. Can. J. Earth Sci. **17**: 307-312.

Wilson, M.V.H. and Williams, R.R.G. 1991. A new Paleocene smelt (Teleostei: Osmeridae) from the Paskapoo Formation of Alberta, Canada, and comments on osmerid phyolgeny. Journal of Vertebrate Paleontology **11**: 434-451. (Name of species: *Speirsaenigma* *lindoei*)

The only other fish taxon known at present from Joffre Bridge Roadcut is Family Amiidae, unidentified as to genus and species and represented by scales and isolated bones only (M.H.V. Wilson, pers. comm.).

Number	Locality Name	System/Period	Series/Epoch	Stage/Age
37	**Joffre Bridge SW Chert Layer**	**Tertiary**	**Paleocene**	

Stratigraphic Horizon	Formation	Member
Horizon B. Chert & Mollusc Layer	**Paskapoo**	

Canada	Alberta	52°16.1'N 113°35.7'W	
black molluscιferous chert. Road cut on S side of highway 11 (previously HWY 596), W of Joffre Bridge.		NE1/4,S13,T38,R26,W4 12U UN 229940	83A/5 AS2737-14

Specimen Number	Identification	Material
6236	Tipulidae	"mollusc"
6238	Tipulidae	larva
6250		
6251	Tipulidae	larva
6253		2 pieces
6266		

Number	Locality Name	System/Period	Series/Epoch	Stage/Age
56	**Joffre Bridge SW Fish Layer**	**Tertiary**	**Paleocene**	

Stratigraphic Horizon	Formation	Member
Horizon A. Fish Layer	**Paskapoo**	

Canada	Alberta	52°16.1'N 113°35.7'W	
greenish gray silty shale, Fe oxide stained surface. Rd. cut on S side of hwy. 11 (old hwy. 596), W of Joffre Bridge		NE1/4,S13,T38,R26,W4 12U UN 229940	83A/5 AS2737-14

Specimen Number	Identification	Material

Number	Locality Name	System/Period	Series/Epoch	Stage/Age
47	**Joffre Bridge SW Insect Layer**	**Tertiary**	**Paleocene**	

Stratigraphic Horizon	Formation	Member
Horizon C. Insect & Plant Layer.	**Paskapoo**	

Canada	Alberta	52°16.1'N 113°35.7'W	
medium grey mudstone. Rd. cut on S side of hwy. 11 (previously HWY 596), W of Joffre Bridge (Wighton site4)		NE1/4,S13,T38,R26,W4 12U UN 229940	83A/5 AS2737-14

Specimen Number	Identification	Material
411	Donacia wightoni	elytra, pt. cpt.
412	Donacia wightoni	elytra, pt. cpt.
413	Donacia wightoni	elytra, pt. cpt.
414	Donacia wightoni	elytra, pt. cpt.
415	Donacia wightoni	elytra, pt. cpt.
416	Donacia wightoni	elytra
6176	Orthoptera	
6177	Tipulidae	"type specimen"
6181	Aeschna sp.	
6184	Orthoptera	
6190	Anisoptera	wing fragment
6239	Tipulidae	
6243	Tipulidae	larva
6244		
6245		
6246		
6247	Tipulidae	
6248	Tipulidae	
6249		
6254		2 pieces
6268	Odonata	wing

6269		
6270	Odonata	
6271		
6272	Odonata	wing
6276	Coleoptera	pt & cpt.
6287	Coleoptera	wing
6296	Heteroptera	
6304		
6305		
6306	Trichoptera	
6307	Trichoptera	
6308	Trichoptera	
6309	Trichoptera	
6310	Trichoptera	
6311	Trichoptera	
6312	Trichoptera	
6313	Trichoptera	wing
6314	Trichoptera	
6315	Trichoptera	
6316	Trichoptera	
6317	Trichoptera	
6318	Trichoptera	
6319	Trichoptera	
6320	Trichoptera	wing, pt & cpt.
6322	Trichoptera	
6323	Trichoptera	
6324	Trichoptera	insect wing
6325	Trichoptera	
6326	Trichoptera	
6327	Trichoptera	wing, pt & cpt.
6337		wings
6345		wings
6355		wings
6356		wings
6357		wings
6358		wings
6359		wings
6360		wings
6362		
6363		wings
6366		Dennis Wighton's insect collection
6367		Dennis Wighton's insect collection
6370		Dennis Wighton's insect collection
6380	Coleoptera	
6387	Coleoptera	2 pieces
6427		insect larva, 2 pieces, field no. 602
6441		larva
6451		Dennis Wighton's insect collection
6472		Dennis Wighton's insect collection
6473		Dennis Wighton's collection
6474		wings, Dennis Wighton's insect
6475		wings, larva, Dennis Wighton's insect
6476		larva, Dennis Wighton's insect
6477		larva, Dennis Wighton's insect
6478		larva , Dennis Wighton's insect

6479		larva, Dennis Wighton's insect
6480		larva, Dennis Wighton's insect
6481		larva, Dennis Wighton's insect
6482		larva, Dennis Wighton's insect
6483		larva, Dennis Wighton's insect
6484		larva, Dennis Wighton's collection
6485		larva, Dennis Wighton's insect
6486		larva, Dennis Wighton's insect
6487		larva, Dennis Wighton's insect
6488		larva, Dennis Wighton's insect
6489		larva, Dennis Wighton's insect
6490		larva, Dennis WIghton's insect
6491		larva, Dennis Wighton's insect
6492		larva, Dennis WIghton's insect
6493		larva, Dennis Wighton's insect
6535		wing
6536		wing
6544	Tipulidae	larva
6545		larva
6546		larva
6547		larva
6548		larva
6549		larva
6550		wing?, 2 pieces, pt. & cpt.
6551		larva
6552		larva
6553		larva
6554		larva
6555		larva
6558		larva
6574	Coleoptera	larva
6575		larva
6577	Coleoptera	larva
6654	Coleoptera	wing, Dennis Wighton's collection
6655	Coleoptera	wing, Dennis Wighton's collection
6656	Coleoptera	Dennis Wighton's collection
6657	Coleoptera	wing, Dennis Wighton's collection
6659	Coleoptera	wing, Dennis Wighton's collection
6660		larva, Dennis Wighton's collection
6661	Coleoptera	wing, Dennis Wighton's collection
6662	Coleoptera	Dennis Wighton's collection
6663	Coleoptera	wing, Dennis Wighton's collection
6664	Coleoptera	wing, Dennis Wighton's collection
6665	Coleoptera	wing, Dennis Wighton's collection
6666	Coleoptera	Dennis Wighton's collection
6667	Coleoptera	Dennis Wighton's collection
6668	Coleoptera	wing, Dennis Wighton's collection
6669	Coleoptera	wing, Dennis Wighton's collection
6670		larva, Dennis Wighton's collection
6671	Coleoptera	wing, Dennis Wighton's collection
6672	Coleoptera	wing, Dennis Wighton's collection
6673	Coleoptera	wing, Dennis Wighton's collection
6674	Coleoptera	Dennis Wighton's collection
6675	Coleoptera	wing, Dennis Wighton's collection
6676	Coleoptera	wing, Dennis Wighton's collection

6678		larva, Dennis Wighton's collection
6679	Coleoptera	wing, Dennis Wighton's collection
6680	Coleoptera	wing, Dennis Wighton's collection
6681	Coleoptera	Dennis Wighton's collection
6682	Coleoptera	wing, Dennis Wighton's collection
6683	Coleoptera	wing, Dennis Wighton's collection
6684	Coleoptera	wing, Dennis Wighton's collection
6685	Coleoptera	Dennis Wighton's collection
6686	Coleoptera	wing, Dennis Wighton's collection
6687	Coleoptera	wings, Dennis Wighton's collection
6688	Coleoptera	wing, Dennis Wighton's collection
6689	Coleoptera	wing, Dennis Wighton's collection
6690	Coleoptera	wings, Dennis Wighton's collection
6691	Coleoptera	Dennis Wighton's collection
6692	Coleoptera	wing, Dennis Wighton's collection
6693	Coleoptera	wing, Dennis Wighton's collection
6694	Coleoptera	Dennis Wighton's collection
6695	Coleoptera	wing, Dennis Wighton's collection
6696	Coleoptera	Dennis Wighton's collection
6697	Coleoptera	Dennis Wighton's collection
6698	Coleoptera	wings, Dennis Wighton's collection
6699	Coleoptera	wing, Dennis Wighton's collection
6701	Coleoptera	wings, Dennis Wighton's collection
6702	Coleoptera	wing, Dennis Wighton's collection
6703		larva, Dennis Wighton's collection
6704	Tipulidae	larva, Dennis Wighton's collection
6706		wing, Dennis Wighton's collection
6707		wing, Dennis Wighton's collection
6708	Coleoptera	Dennis Wighton's collection
6709		insect? Dennis Wighton's collection
6711		larva, Dennis Wighton's collection
6713		larva, Dennis Wighton's collection
6714		larva, Dennis Wighton's collection
6715		larva, Dennis Wighton's collection
6716		larva, Dennis Wighton's collection
6717		larva, Dennis Wighton's collection
6718		larva, Dennis Wighton's collection
6736	Trichoptera	wing
6737		several specimens
6738		
6739		mollusc
6740		
6741		several specimens
6742		
6743		
6744		
6745		wings
6746		
6747		
6748		
6790		
6791		
8110		bug bits, pt & cpt
8111		bug bits

APPENDIX C

PALYNOLOGY

PALEONTOLOGICAL REPORT
RAPPORT DE PALÉONTOLOGIE

CANADA
1842
GEOLOGICAL SURVEY - COMMISSION GÉOLOGIQUE

04-ARS-1995

Applied research report on seven middle Paleocene samples from central Alberta (NTS 93N/14; Zone 9, 6190525 N, 367325 E) as requested by G. Hoffman (Department of Botany, B414 Biological Sciences Building, University of Alberta, Edmonton T6G 2E9). Copy to J.F. Lerbekmo (Department of Geology, University of Alberta)

DEPARTMENT OF NATURAL RESOURCES CANADA
MINISTÈRE DES RESSOURCES NATURELLES CANADA

Tricolpites bathyreticulatus Stanley, 1965
Triporopollenites plektosus Anderson 1960
"Virgo" rallus (Stanley, 1965) comb. nov.
Ulmipollenites undulosus Wolfe, 1934

GENERAL COMMENTS

These samples are from an important middle Paleocene reference locality, as there is an associated mammalian fauna (Fox, 1990) and the paleomagnetostratigraphy (Lebekmo et. al., 1992) of the section is known.

Age: The upper Joffre locality has been assigned to the middle Tiffanian based on microvertebrates (Ti3; Fox, 1990), the upper part of the 26r magnetozone and the palynological P4 or *Caryapollenites wodehousei* Zone (Demchuck, 1990; Lerbekmo et al., 1992). The *Caryapollenites wodehousei* Zone is distinguished by the first occurrence of two species of *Caryapollenites*, *C. wodehousei* and *C. imparalis* accompanied by a third species *Caryapollenites prodromus* which originates in the underlying *Aquilapollenites spinulosus* Zone. In the eight samples examined only five pollen grains possibly assignable to *Caryapollenites prodromus* were seen out of the nearly 2000 miospores counted and the over 100,000 encountered in the area scanned. No specimens of either *Caryapollenites wodehousei* or *C. imparalis* were seen which highlights the tenuous nature of the application of the *Caryapollenites wodehousei* zone.

The biostratigraphically significant aspects of the upper Joffre Bridge locality are:

- the presence of a relatively small and rounded form of *Tilia*-like pollen (*Intratriporopollenites minimus*) with a diameter of 28.0 (avg. 30.3) 34 μ and a distance of 23 to 32 μ from tip of colp to tip of colp.
- an abundance of *Brevicolporites colpella* with only one specimen of the more evolved species *Phaseoliidites stanleyi* seen.
- an abundance of *Virgo rallus*, *Ulmipollenites undulosus*, and *Aquilapollenites spinulosus*.
- the effective dominance of the Juglandaceae-suite by *M. leffingwellii*, *M. marylandicus*, *M. microfoveolatus*, *M. ventifluminis* and *M. wyomingensis*.
- an absence of *Syncolporites minimus* and near absence of *Triporopollenites plektosus*.

Other comments: G. Hoffman has collected and identified abundant macrofossils of what are considered to be a liverwort and *Spirodela* from the horizon spanned by sample SLA-93-12-2. In addition to sample SLA-93-12-2, matrix directly associated with the macrofossils, as supplied by G. Hoffman, was also run (P3970-8). G. Hoffman's question was whether dispersed liverwort spores were present in the rock matrix. Four specimens of *Zilvisporis* sp. were seen in sample SLA-93-12-2 and several were observed in sample SLA-93-12-7, from below the coal horizons. These are considered to be bryophytic. Single specimens and clumps of a species of an spinous "algal cyst" are abundant in the residue of SLA-93-12-2 and in P3970-8.

Of additional interest was the presence of microsporangial clumps of a spinate, monoporate angiosperm pollen usually referred palynologically to the genus *Pandaniidites*, alluding to a widely held belief that it is derived from the genus *Pandanus* but herein called *Echigraminidites*. The referral of the spinous, monoporate pollen to *Echigraminidites* is based on their having a distinctly two-layered wall and the spine bases restricted to the tectum. As extant *Spirodela* also produces a monoporate spinate pollen, the exceptionally high relative abundance (26 %) of *Echigraminidites* found associated with *Spirodela* plant macrofossils in P3970-8 is strongly suggestive that the source plant for monoporate pollen at the Joffree locality is *Spirodela*. This disallows a tropical or warm temperate climatic argument based on the presence of *Pandanus*-like pollen.

Report 04-ARS-1995

Applied research report on seven middle Paleocene samples from central Alberta (NTS 93N/14; Zone 9, 6190525 N, 367325 E) as requested by G. Hoffman (Department of Botany, B414 Biological Sciences Building, University of Alberta, Edmonton T6G 2E9). Copy to J.F. Lerbekmo (Department of Geology, University of Alberta)

The relevant parts of any manuscript prepared for publication that paraphrase or quote from this report should be referred to the Paleontology Subdivision, Calgary for possible revision.

The attached spread sheet and graphics provide the details on the palynological assemblages recovered from the upper part of the Joffre Bridge section in samples collected by A.R. Sweet and O. Catuneanu August, 1993 and from a sample containing plant macrofossils collected by G. Hoffman. The recovery and preservation was good to excellent in all the listed samples.

Sample P3970-1; SLA-93-12-1; C-221822.

Sample P3970-2 and P3970-8; SLA-93-12-2; C-221823.

Sample P3970-3; SLA-93-12-3; C-221824.

Sample P3970-4; SLA-93-12-4; C-221825.

Sample P3970-5; SLA-93-12-5; C-221826;

Sample P3970-6; SLA-93-12-6; C-221827;

Sample P3970-7; SLA-93-12-7; C-221828;

FORMAL TAXA USED IN APPENDIX I

Alnipollenites trina (Stanley) Norton, 1969 emend.
Alnipollenites verus Potonié ex Potonié, 1931
Aquilapollenites spinulosus Funkhouser, 1961
Arecipites microreticulatus Anderson, 1960
Brevicolporites colpella Anderson, 1960
Caryapollenites prodromus Nichols and Ott, 1978
Dyadonapites reticulatus Tschudy, 1973
Fraxinoipollenites variabilis Stanley, 1965
Intratriporopollenites minimus Mai, 1962
"Maceopolipollenites" actinus (Nichols and Ott, 1978) comb. nov.
"Maceopolipollenites" leffingwelli (Nichols and Ott, 1978) comb. nov.
"Maceopolipollenites" marylandicus (Groot and Groot, 1962) comb. nov.
Momipites microfoveolatus (Stanley) Nichols 1973
Momipites wyomingensis Nichols and Ott, 1978
Paraalnipollenites alterniporus (Simpson) Srivastava 1975
Parviprojectus striatus Mtchedlishvili, 1961
Penetetrapites inconspicuus Sweet 1986
Phaesoliidites stanleyii Elsik, 1968
Retitricolpites crassus Samoilovitch 1965
Rhoipites globosus Stanley, 1965

REFERENCES

Demchuck, T.D. 1990. Palynostratigraphic zonation of Paleocene strata in the central and south-central Alberta Plains. Canadian Journal of Earth Sciences, v. 17, p. 1263-1269.

Fox, R. C. 1990. The succession of Paleocene mammals in western Canada. In Thomas M. Brown and Kenneth D. Rose, eds., Dawn of the Age of Mammals in the northern part of the Rocky Mountain Interior, North America: Boulder, Colorado, Geological Society of America, Special Paper 243, p. 51-70.

Lerbekmo, J.F., Demchuck, T.D., Evans, M.E. and Hoye, G.S. 1992. Magnetostratigraphy and biostratigraphy of the continental Paleocene of the Red Deer Valley, Alberta, Canada, v. 40, p. 24-35.

ARSweet

A. R. Sweet

Paleontology Subdivision
Institute of Sedimentary and Petroleum Geology
Calgary, Alberta.

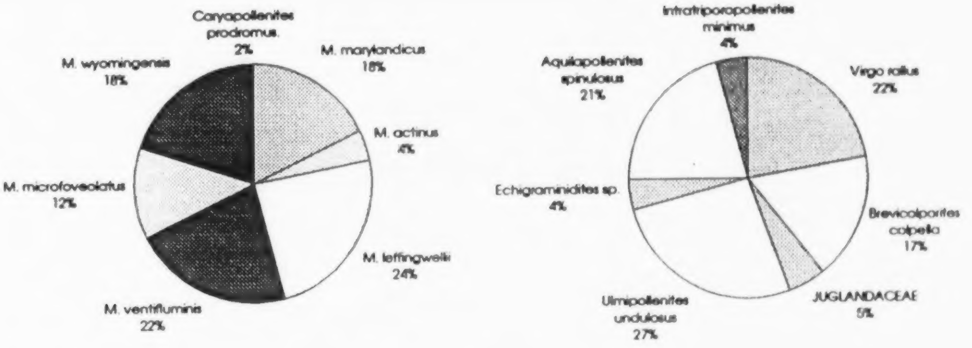
APPENDIX I

	Joffree Bridge (Upper) (SLA-93-12)								
C no	221822	221823	221824	221825	221826	221827	221828		
P no	3970-1	3970-2	3970-3	3970-4	3970-5	3970-6	3970-7	3970-8	**Total**
TAXA									
Sigmopollis sp.	2	0	0	5	1	1	6		15
Other algae (Shizophacus)	2	C	A	R	0	0	0	2	2
Total others	4	0	0	5	1	1	6		17
									0
Gymnosperms									0
T/C/T	190	202	175	132	161	127	102	222	1089
Bisaccate pollen	2	0	1	1	8	2	2	5	16
Cycadopites sp. (Ginkgo)	R	C	1	4	0	3	R	5	8
Total gymnosperms	192	202	177	137	169	132	104	232	1113
									0
Spores									0
Laevigatosporites sp.	4	9	13	0	8	4	1	5	39
Cyathidites sp.	4	0	0	0	2	1	1	3	8
Osmundacidites sp.	0	R	2	0	1	0	1	2	4
Equisetum sp.	3	0	2	0	0	0	0		5
Bohemiasporis sp. 2	0	0	0	0	0	0	R		
Zilvisporis sp.(Riccia)	0	R	0	0	0	0	R		0
Other miospores	0	0	R	R		R	R		0
Total spores	11	9	17	0	11	5	3	10	56
									0
Angiosperms									0
other Betulaceae	4	4	9	6	14	3	2	5	42
Alnipollenites trina	0	0	0	0	0	0	0		0
Alnipollenites verus	R	0	R	R	S	R	R		0
Paraalnipollenites alterniporus	R	R	0	0	0	R	R	R	0
Momipites/Maceo. /Carya	C	C	0	1	1	2	1	1	50
Maceopolipollenites. actinus	2								2
M. leffingwelli	1	1		6		4			12
M. marylandicus	2	2		1		2	2		9
M. ventifluminis	4			2			5		11
Momipites microfoveolatus	1	1		2			2		6
M. wyomingensis	1	2		1			5		9
Caryapollenites prodromus.	R	R	0	R	0	1	R		1
Ulmipollenites undulosus	R	5	7	4	6	4	6	10	32
Triporopollenites plektosus	0	0	0	0	0	0	R		0
Rhoipites globosus	0	1	16	0	7	3	0	2	27
Nyssapollenites sp.	0	0	R	0	0	0	R		0
Rhus sp.	0	0	0	0	0	0	0		0
Brevicolporites colpella	2	3	6	4	6	R	R	3	21
Phaseoliidites stanleyi?	0	0	0	R	0	0	0		0
Tricolpate pollen	5	12	10	94	22	89	75	22	307

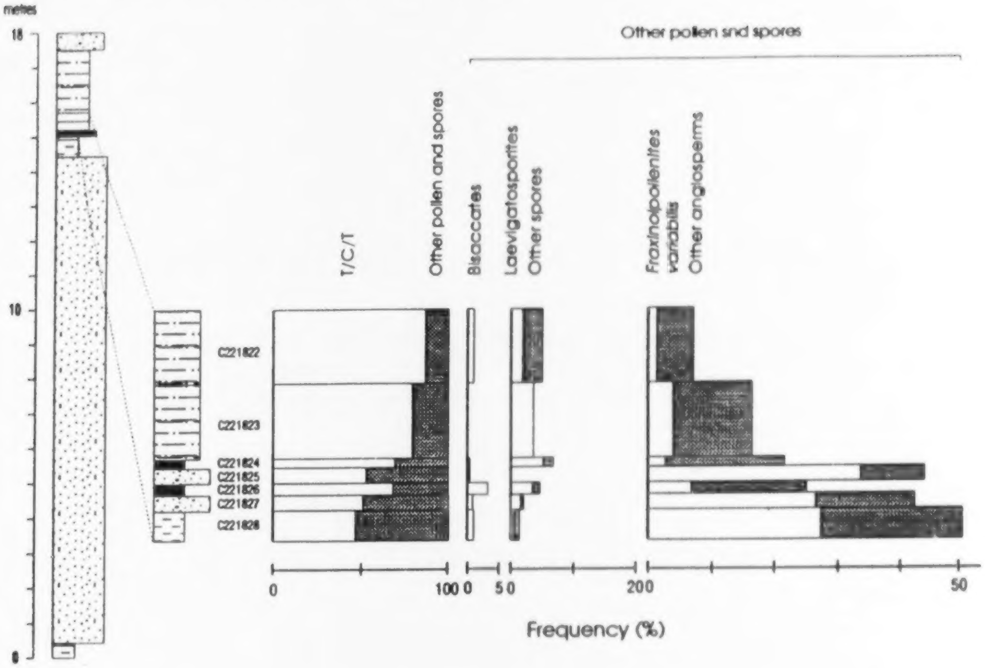
Fraxinoipollenites variabilis	3	10	7	86	18	68	61	21	253
Retitricolpites crassus	0	R	2	0	0	5	R		7
Cercidiphyllum sp.	1	0	1	4	1	14	9	1	30
Tricolpites bathyreticulatus	0	0	0	0	0	0	R		0
Tricolpites lillei Couper in N&H	0	0	0	R	0	0	0		0
Striatopollis sp.	0	0	0	R	0	0	1		1
Other tricolpate pollen	1	2	0	4	3	2	4		16
Liliacidites sp.	0	0	0	0	0	0	3		3
Arecipites microreticulatus	0	0	0	0	0	0	0	8	
Arecipites sp.(margo)	3	18	3	1	0	0	R		25
Echigraminidites sp.	0	R	0	1	0	2	2	26	5
Sparganium sp.	0	0	0	0	0	0	R		0
Erdtmanipollis sp.	R	R	C	C	1	R	C		1
Virgo rallus	2	0	0	2	1	6	16		27
Dyadonipites reticulatus	A	0	0	0	R	0	0		0
Penetetrapites inconspicuus	R	0	0	0	0	1	3		4
Aquilapollenites spinulosus	R	C	5	A	2	5	13		25
Cranwellia subtilis	0	0	0	R	0	2	0		2
Parviprojectus striata	0	0	R	R	0	R	0		0
Intratriporopollenites minimus	R	R	2	R	0	1	2		5
Other angiosperms	0	S	0	2	0	0	0		2
Total angiosperms	16	43	58	115	60	119	123	77	534

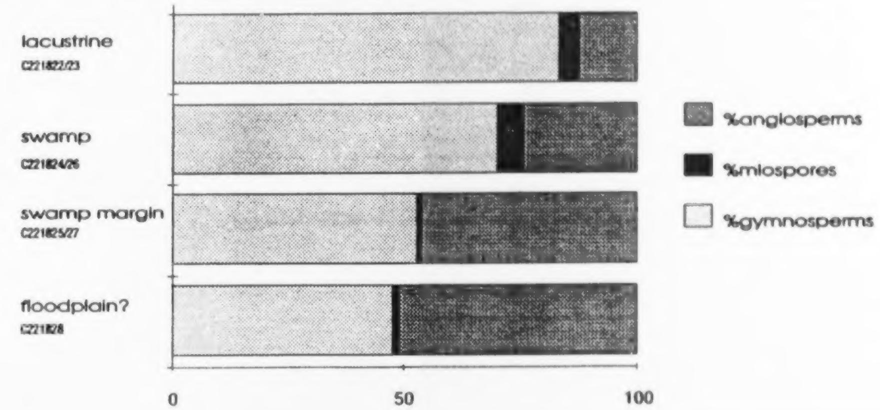
TOTAL1	219	254	252	252	240	256	230		1703
TOTAL2	223	254	252	257	241	257	236		1720
%T/C	86.76	79.53	69.44	52.38	67.08	49.61	44.35		
OSP	13.24	20.47	30.56	47.62	32.92	50.39	55.65		
%BIS	0.91	0.00	0.40	0.40	3.33	0.78	0.87		
%MIO									
%LAE	1.83	3.54	5.16	0.00	3.33	1.56	0.43		
%MOT	3.20	0.00	1.59	0.00	1.25	0.39	0.87		
%FRAX	1.37	3.94	2.78	34.13	7.50	26.56	26.52		
%AOT	5.94	12.99	20.24	11.51	17.50	19.92	26.96		
%gym	87.67	79.53	70.24	54.37	70.42	51.56	45.22		
% mio	5.02	3.54	6.75	0.00	4.58	1.95	1.30		
% ang	7.31	16.93	23.02	45.63	25.00	46.48	53.48		
	Total	%	3970-8	%					
Virgo rallus	27	22.31	0	0					
Triporopollenites plektosus	R	0.00	0	0					
Brevicolporites colpella	21	17.36	3	7.5					
JUGLANDACEAE	6	4.96	1	2.5					
Ulmipollenites undulosus	32	26.45	10	25					
Echigraminidites sp.	5	4.13	26	65					
Aquilapollenites spinulosus	25	20.66	0	0					
Intratriporopollenites minimus	5	4.13	0	0					
Total	121	100.00	40	100					
	lac	swamp	sw mar	fpl					
%gymnosperms	83.60	70.33	52.96	47.71					
%miospores	4.28	5.66	0.98	1.38					
%angiosperms	12.12	24.01	46.06	50.92					
lac=lacustrine									
sw mar = swamp margin									
fpl = floodplain									

Pie diagrams presenting the average relative abundance of: 1 (left hand diagram) - species of Juglandaceae pollen recorded from the Joffre samples. The percentages are based on the total of 50 Juglandaceae pollen specimens (see spread sheet); 2 (right hand diagram) - percentage of a selected group of angiosperm pollen species. The percentages are based on a total of 121 specimens of the selected species (see spread sheet).



RELATIVE ABUNDANCE DIAGRAM FOR JOFFRE BRIDGE



COMPARISON OF DEPOSITIONAL ENVIRONMENTS